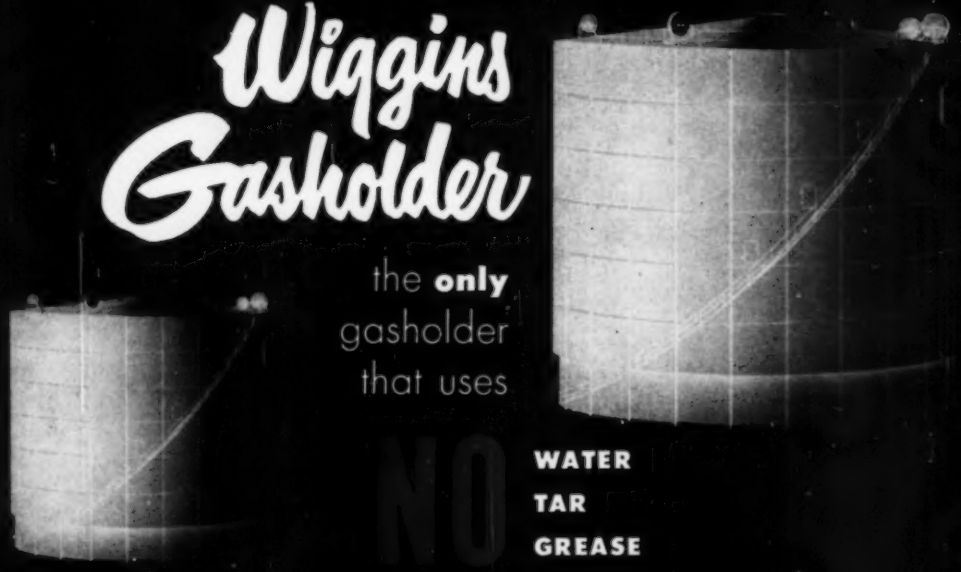
APRIL 1951

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

Wiggins Gasholder



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Volume 47
Number 4

Chemical Engineering Progress

APRIL
1951

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FLOW INDICATOR AND TRANSMITTER OR ECONOMICAL TOTALIZER

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A direct connected differential pressure instrument.

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The V/A Cell provides an entirely new approach to flow metering. Combining the advantages of the variable-area meter and the orifice meter, it eliminates the disadvantages of both. It is a differential pressure instrument without the need for exterior purges, elaborate manifold systems, mercury, condensate chambers, bellows, and seals.

The V/A Cell is supplied in two models, for pressures up to 3000 psi, for temperatures up to 300° F. The instrument may be installed anywhere up to 60 feet from the main-line orifice.

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Crane Ferrosteel valves—recommended especially for ammonia service—are also ideal for process piping that requires heavy duty valves of all-iron and steel materials. Special Crane seating design and rugged construction combine to make these valves highly effective for safe and economical handling of hazardous or noxious liquids and gases. They minimize the danger of costly fluid losses with important features like these:

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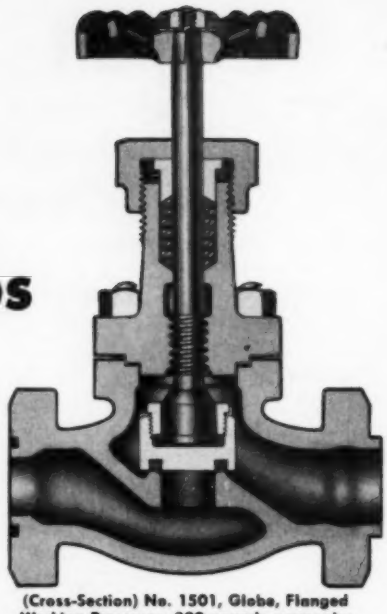
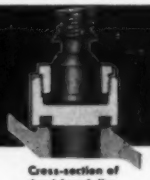
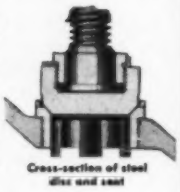


(Cross-Section) No. 1501, Globe, Flanged
Working Pressures: 300 pounds ammonia; 500 pounds oil, gas, or air up to 100° F.
Sizes: ½ to 4-inch.
Tested at 300 pounds Air-under-Water

CHOICE OF TWO TIGHT-SEATING DESIGNS



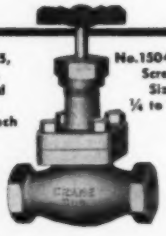
Cross-section of lead-faced disc



Cross-section of steel disc and seat

Crane special lead-faced disc—with facing securely rolled into machined dovetail—seats against crowned face of integral body seat to assure tightness in service. Where temperature or corrosive action does not allow use of lead, these valves can be supplied with a case-hardened steel disc and steel seat ring.

No. 1505, Angle, Screwed Sizes: ¼ to 3-inch



No. 1504, Globe, Screwed Sizes: ¼ to 3-inch

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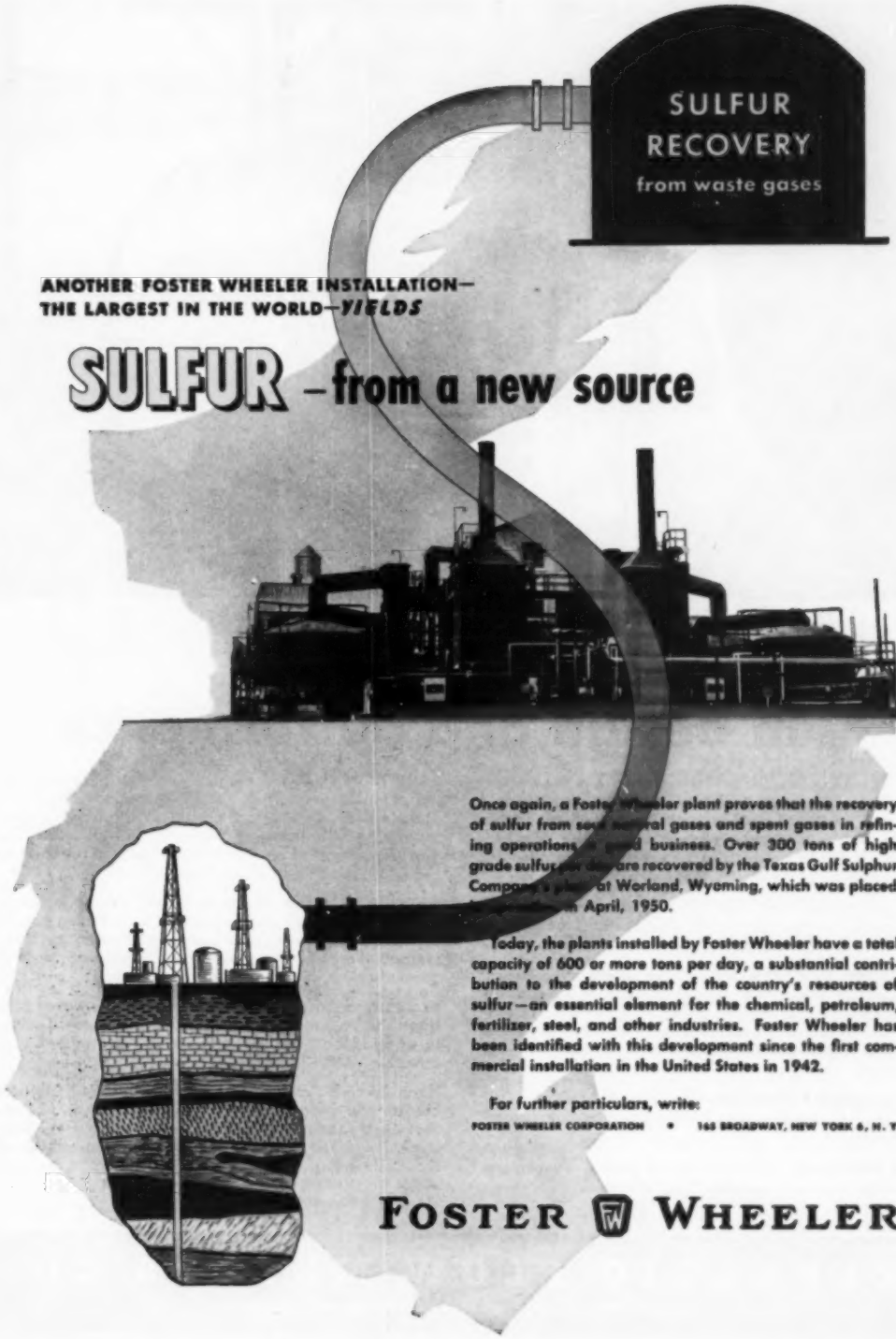

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Once again, a Foster Wheeler plant proves that the recovery of sulfur from sour natural gases and spent gases in refining operations is good business. Over 300 tons of high grade sulfur per day are recovered by the Texas Gulf Sulphur Company's plant at Worland, Wyoming, which was placed in operation in April, 1950.

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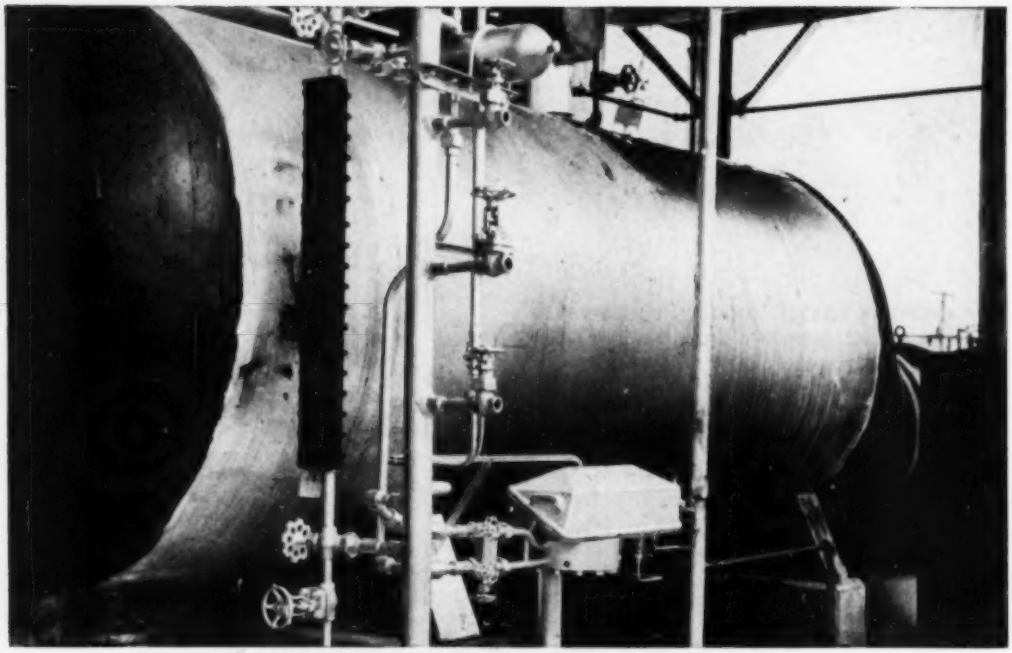


Republic Transmitter measuring level in reboiler

DIFFERENT . . . in design and performance

The Republic Pneumatic Transmitter is a device for converting process variables, such as flow, level, pressure or liquid density, into air pressures. These air pressures are a direct measure of the process variables or can be used as the measuring impulse for the actuation of an automatic controller.

The force-balance method of measurement, as employed by the Republic Pneumatic Transmitter, offers many inherent advantages such as:

AMBIENT TEMPERATURE — The effect of ambient temperature variations on the accuracy of a Republic Transmitter is negligible. Since all parts are equally affected by temperature changes, force and leverage relationships are not disturbed and accuracy is unimpaired.

AIR SUPPLY PRESSURE — The effects of changes in air supply pressure is so small that it is guaranteed negligible.

LINE PRESSURE — The effect of variations in line pressure has been completely eliminated.

SENSITIVITY — Due to the negligible motions required for complete operation of all parts for full scale changes, no appreciable hysteresis results from reversal of direction of measurement change. The hysteresis loop is so small that it is undetectable by ordinary means, being less than 1/20 of 1%.

ACCURACY — The accuracy of the Republic force-balance method of measurement is higher than can be consistently secured and maintained with any other method. Transmitting pressure vs. measured force is guaranteed within ½ of 1% of meter range.

In addition to these five important features, the Republic Pneumatic Transmitter is extremely flexible in application, easy to service and of rugged construction.

If you have a flow, level, pressure or liquid density metering or control problem may we suggest that you investigate the Republic Pneumatic Transmitter? Data Book No. 1002, which contains complete details of this instrument, will be mailed to you upon request. Write for it today!

REPUBLIC FLOW METERS CO.

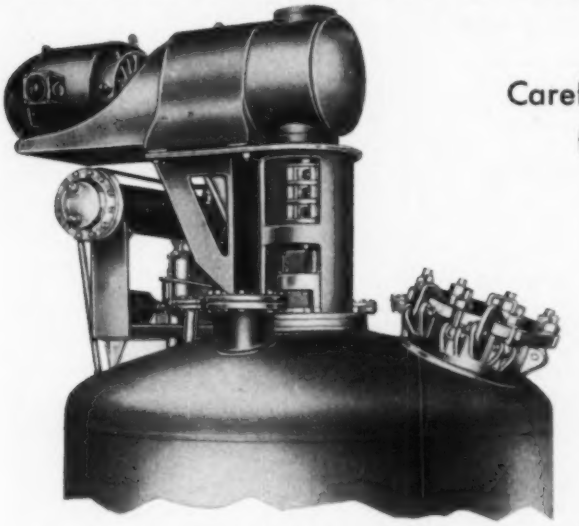
2240 Diversey Parkway, Chicago 47, Illinois

For Smooth Driving Action!

Easy Accessibility of Parts!

Long Trouble-Free Service!

Struthers Wells Processing Vessels

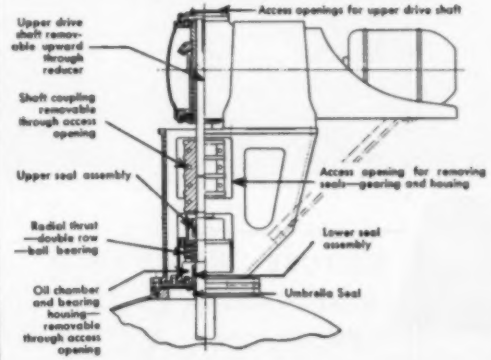


are equipped with
Carefully Designed Agitator Drives
for Extreme Temperature
and Pressure Service

NOTE THESE FEATURES . . .

- ★ All parts are accessible for quick and easy removal and replacement.
- ★ Agitator Drive Shaft is radially supported at top and bottom of the drive providing a spread of bearings practically equal to the vertical space occupied by the drive.
- ★ Agitator Drive Shaft thrust is taken by radial-thrust double row ball bearing located in close proximity to pressure seals insuring accurate centering and a minimum end-wise motion of the shaft at locations of seals.
- ★ Seal parts are carbon and non-corrosive metals to withstand corrosion in the same degree as the metal used in the vessel.
- ★ Oil circulating unit provides equalized liquid pressure seal, which also lubricates and cools the working parts.
- ★ An umbrella seal is provided to accumulate seepage of oil across the seal face and eliminate contamination of vessel content.
- ★ Standard units are available for full vacuum or pressures up to 500 psi. with processing temperatures up to 650° F.
- ★ Made in five sizes—ranging from 1 to 50 horsepower.

Cross Sectional View Shows Accessibility of Parts


Access openings for upper drive shaft
Upper drive shaft removable upward through reducer
Shaft coupling removable through access opening
Upper seal assembly
Access opening for removing seals—gearing and housing
Radial thrust —double row —ball bearing
Lower seal assembly
Oil chamber and bearing housing—removable through access opening
Umbrella Seal

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BROWN FINTUBE *Thermo-Flo* PROCESS HEATERS

Newly designed unit shortens heating and cooling cycle... cutting equipment and processing costs

● Brown Fintube THERMO-FLO Process Heaters offer many advantages for process heating and cooling, and — including the cost of the *single shell* tank — usually *cost less* than a jacketed vessel of equivalent capacity.

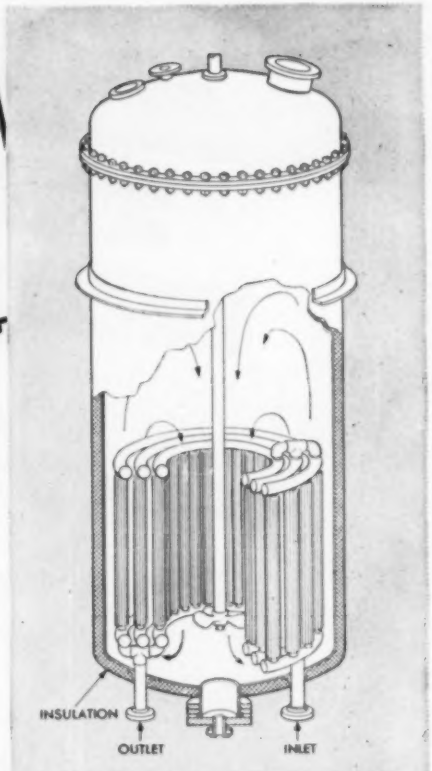
SHORTENS PROCESSING CYCLE — Use of Brown integrally bonded fintubes provides 4 to 10 times the heating surface of the same length of bare pipe coil, or many times the area offered by a jacketed kettle of equivalent size. This shortens the processing cycle, and permits more material to be handled in *smaller* and *less costly* vessels.

EFFICIENT HEAT TRANSFER — The material adjacent to the fintubes is heated quickly, and rises rapidly along the finned sections, forming a thermal siphon within the tank. This natural flow is sometimes augmented by the induced flow of an agitator, especially if quick mixing is desired.

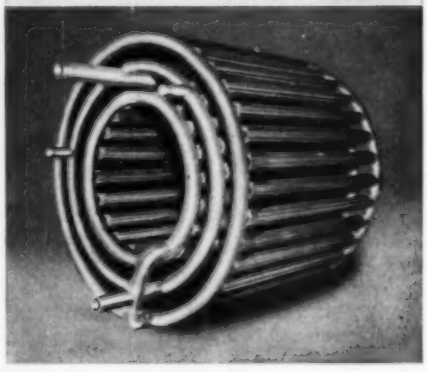
AVOIDS CRACKING AND COKING — The large heating area of the finned tubes permits processing with low temperature differential between the heat transfer surface and the material — minimizing damage to the material from localized overheating.

MEETS ANY REQUIREMENT — Brown THERMO-FLO Process Heaters are available with single or multiple circular banks — in any height and diameter to meet specific duties. Furnished in low carbon or stainless steel, or nickel, monel, everdur or other alloys — as single heaters or complete with tank — to meet individual conditions.

Price and delivery information furnished promptly. Write for Bulletin No. 492. It gives full details.



The installation diagram and heater coil illustrated herewith is only one of many applications, and types, of these heaters and coolers available.



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Think of this sign first . . . . . for **Ethylene** *Manufacturing Facilities*

The Lummus reputation for keeping its sights leveled at highly practical objectives is of particular value in the designing and constructing of ethylene manufacturing facilities. The very stature of ethylene—most important of hydrocarbon raw materials for petroleum chemical synthesis—should make such a point of view attractive to industry.

First, Lummus places emphasis on processing for higher yields and lower costs. Detailed processing and engineering studies dictate the scheme to be employed for specific operations. The company's fund of knowledge covering all commercially-applied techniques for making ethylene carries on from there. Lummus' pilot plant and development work have produced important tools to achieve maximum performance and flexibility. Special Lummus cracking heaters meet specific requirements for converting ethane, propane, or mixtures of both to an ethylene-rich effluent.

Second, Lummus places emphasis on the design of ethylene units for lower initial outlay, thus increasing the refiner's profit margin and diversity of income. This is extended to include recognition of metals-availability in the period ahead, as well as planning for rock-bottom maintenance and upkeep costs.

Third, Lummus recognizes the special responsibility of handling confidential information in accordance with the best interests and desires of the customer.

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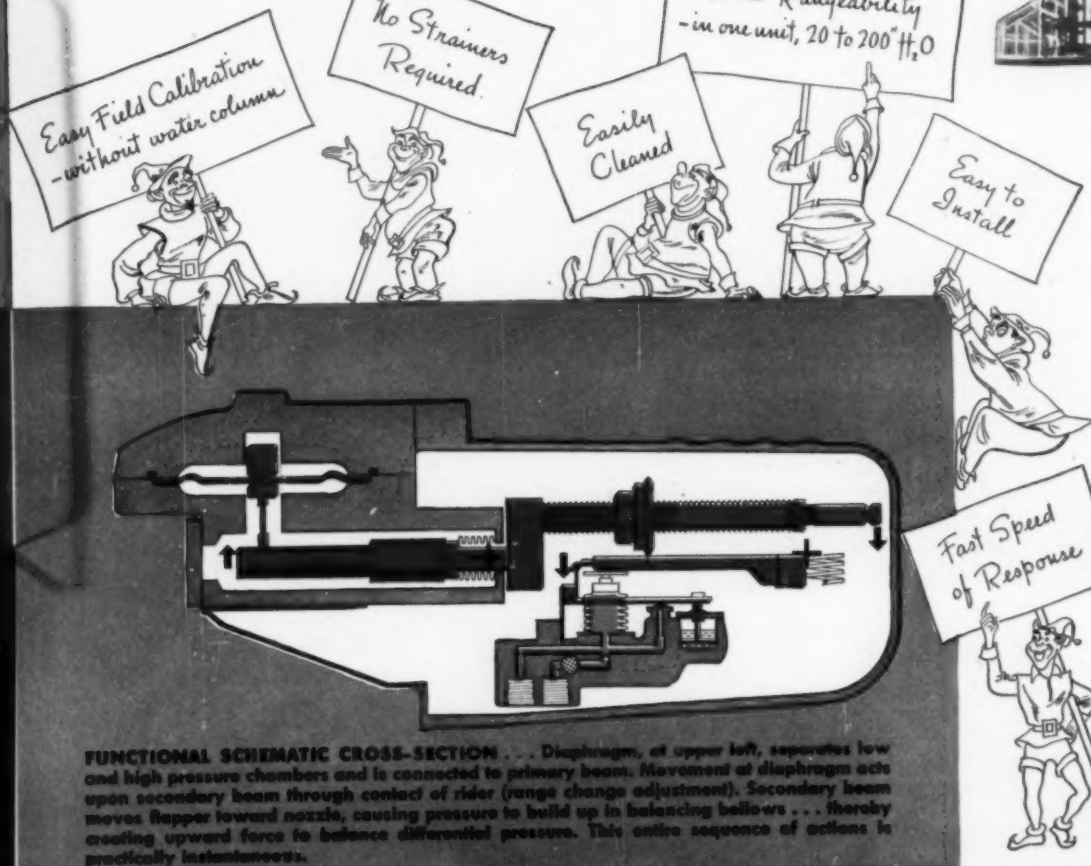
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Easy to Install
Fast Speed of Response

FUNCTIONAL SCHEMATIC CROSS-SECTION . . . Diaphragm, at upper left, separates low and high pressure chambers and is connected to primary beam. Movement at diaphragm acts upon secondary beam through contact of rider (range change adjustment). Secondary beam moves flapper toward nozzle, causing pressure to build up in balancing bellows . . . thereby creating upward force to balance differential pressure. This entire sequence of actions is practically instantaneous.

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the New BROWN DIFFERENTIAL CONVERTER

(pneumatic-balance flow transmitter)

AFTER long and rigorous testing in the field, the Brown Differential Converter is ready to set new high standards of simplicity and precision in the measurement and transmission of flow.

Operating on the pneumatic-balance principle, this compact and light-weight unit converts differential pressure at the orifice into a proportionate output air pressure which is a measure of flow. All adjustments . . . such as the range change which is continuous from 0-20 inches of water up to 0-200 inches of water . . . are easily and simply made, without special tools or extra parts.

Applicable to a wide range of continuous processes, the Brown Differential Converter is the fore-runner of an entirely new series of pace-setting developments made possible through Brown *Creative Instrumentation*. For detailed information write for a copy of new Catalog No. 2281 . . . and call in our local engineering representative for a discussion of your process needs. Offices in more than 80 principal cities of the United States, Canada and throughout the world.

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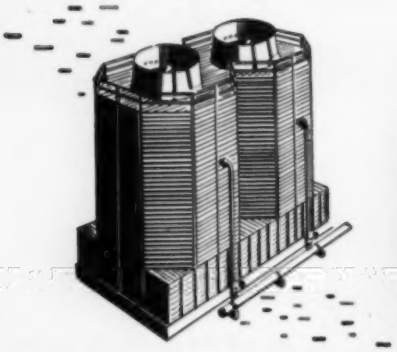

FLUOR COUNTERFLO COOLING TOWERS offer many unique features — all worth looking into!

When selecting cooling towers, it pays to look into the structural and mechanical design features of a Fluor Counterflo Cooling Tower. It is here that the difference between one cooling tower and another is evident—where the difference in structural stability, maintenance of mechanical equipment, and quality appearance lies.

The illustration at right—accurate in every detail—is the way your Fluor Counterflo Cooling Tower will look with a portion of the exterior wall removed. Note the exclusives, the extras, that make Fluor Cooling Towers a wise buy. When *dependable* performance, *low* maintenance, and *quality* appearance is essential or desirable in your plant or process operations, look into a Fluor Counterflo Cooling Tower.

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Fluor Counterflo Induced-Draft Cooling Towers incorporate many important design features which cut the cost of maintenance and improve the appearance of cooling equipment installations.

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DOUBLE-WALL SHEATHING

TOWER STRUCTURE

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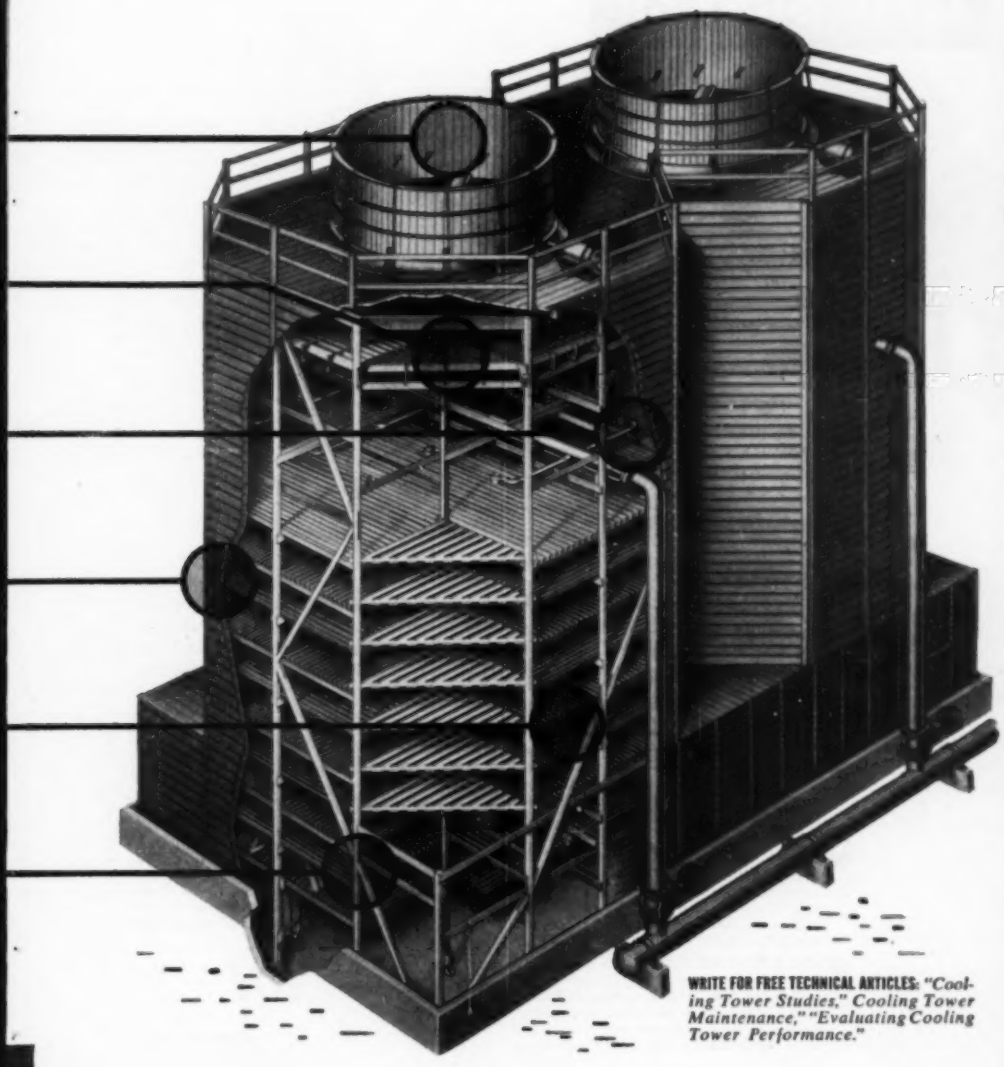

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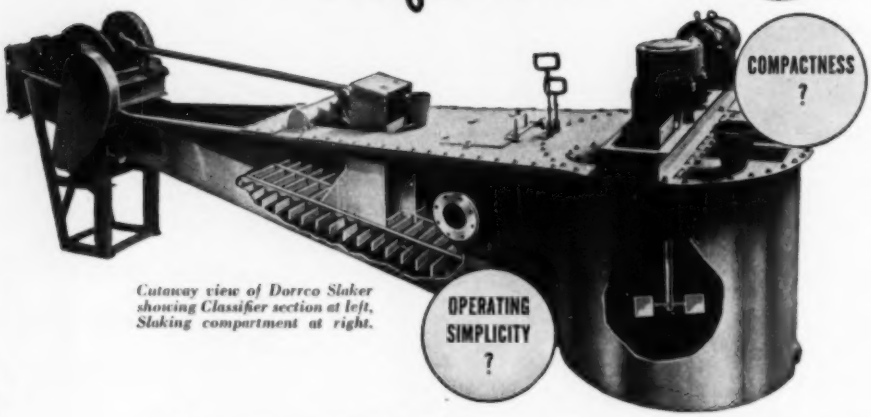
HIGH EFFICIENCIES ?

LOW FIRST COST ?

LOW MAINTENANCE COST ?

do you want . . .



Cutaway view of Dorrco Slaker showing Classifier section at left, Slaking compartment at right.

Chances are you want them all . . . and you can get them all with a Dorrco Slaker . . . the only available unit that does the complete job of slaking and effective grit removal in a single tank. One of the six standard sizes . . . ranging in capacity from 5 to 200 tons of CaO per 24 hours . . . will be right for your slaking problem if you need more than 5 tons per day. Write for Bulletin #7281 for more complete information.

With the Dorrco Slaker you get . . .

- **HIGH EFFICIENCIES . . .** large unit capacity because of tank design and rapid hydration because of mechanical agitation add up to maximum overall efficiency.
- **LOW INSTALLATION COST . . .** the self-contained Dorrco Slaker is shipped almost completely assembled. Erection is easy . . . no field welding . . . no costly piping or launders to connect Slaker and Classifier.
- **LOW MAINTENANCE COST . . .** replaceable 1" thick white iron liners on sides and bottom of Slaker tank minimize abrasion and corrosive problem. If needed, eventual replacements are inexpensive. All bearings are above solution level.
- **NEAT, COMPACT INSTALLATION . . .** The Dorrco Slaker eliminates the usual unsightliness of the slaking operation. It is readily ventilated and minimizes operating hazards.
- **OPERATING SIMPLICITY . . .** necessary only for operator to check periodically the rate of lime and water addition. Control instruments are available to reduce operating attention to occasional observation only.

BETTER TOOLS *today* TO MEET TOMORROW'S DEMAND

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Cleaver-Brooks Compression Distillation . . . The Most Economical Method of Evaporation

Here's Why:

The table shows the approximate costs of operation per 1000 gals. of evaporated water with a Cleaver-Brooks Compression Evaporator as compared with standard multi-effect steam evaporators.

OPERATING DATA	STEAM EVAPORATORS					Cleaver-Brooks Compression Evaporation
	Single Effect	Double Effect	Triple Effect	Quadruple Effect	Quintuple Effect	
Pounds water evaporated per pound steam input from boiler	0.9	1.75	2.5	3.2	4.0	.....
Pounds steam required per 1000 gallons water evaporated	9250	4750	3325	2600	2070	200
Gallons condenser water required per 1000 gallons water evaporated	33,300	16,650	11,100	8,325	6,650	none
Steam cost per 1000 gallons water evaporated, based on steam at $.80 per 1000 pounds	$7.40	$3.80	$2.66	$2.08	$1.66	$.16
Condenser water cost per 1000 gallons water evaporated based on water at $.10 per 1000 gallons	$3.33	$1.66	$1.11	$0.83	$0.66	none
Electric Power Consumption per 1000 gallons water evaporated	10 KWH	6 KWH	6 KWH	6 KWH	6 KWH	60 KWH
Electric Power cost per 1000 gallons water evaporated based on power @ $.01 per KWH	$.10	$.06	$.06	$.06	$.06	$0.60
Total Water & Energy cost per 1000 gallons water evaporated	$10.83	$5.52	$3.83	$2.97	$2.38	$0.76

The concentrating of chemical solutions for valuable recovery or for disposal can be done economically with compression distillation.

The recovery of pickling liquors, the concentration of waste proteins, the concentration of waste pulp liquors, are just a few of the process problems which can be solved through vapor compression distillation at less cost.

Cleaver-Brooks is constantly called upon to evaluate chemical process problems in terms of the vapor compression cycle.

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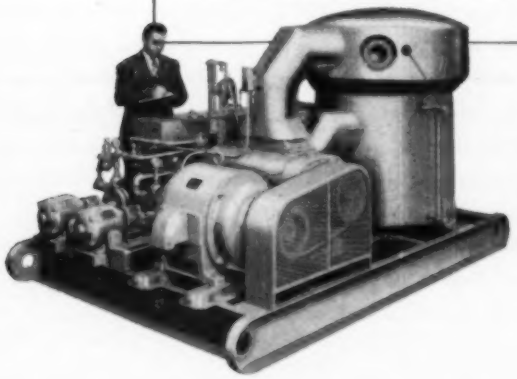

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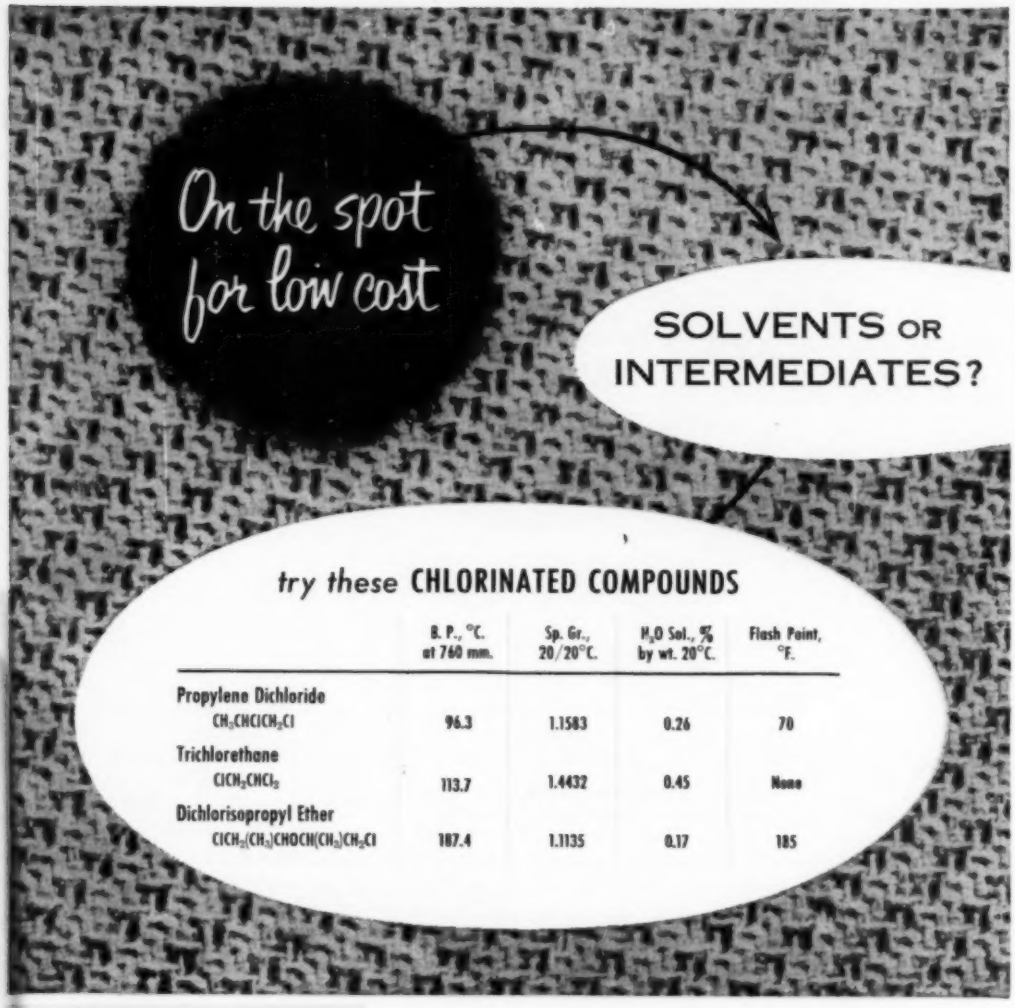

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Propylene Dichloride $CH_3CHClCH_2Cl$	96.3	1.1583	0.26	70
Trichlorethane $ClCH_2CHCl_2$	113.7	1.4432	0.45	None
Dichlorisopropyl Ether $ClCH_2(CH_3)CHOCH(CH_3)CH_2Cl$	187.4	1.1135	0.17	185

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OPINION AND COMMENT

CONSERVING TECHNICAL MANPOWER

THE Manpower Commission of the Engineers Joint Council submitted its report to the National Security Resources Board Dec. 20, 1950. This report is in response to the request that the E.J.C. prepare a program "for the most effective utilization of engineers in the national effort and make recommendations as to how such a program could be best administered." The Commission accepted and endorsed the earlier recommendations of "The Six Committees" concerning the training of scientific, professional and specialized personnel and the utilization of such personnel. It then proposed the creation by act of Congress of a "Reserve" chosen from the registration "of every man up to the age of 70 who has a Bachelors Degree with a major in one of the critical fields of engineering or who is enrolled in a program of training leading to a Bachelors or higher degree in one of these fields, or who is employed in one of these fields." The "Reserve" would be administered by a National Engineering Personnel Board with powers paralleling those of the Selective Service Boards.

While the idea of an engineering reserve has much to commend it, new legislation and the creation of new administrative machinery are involved. On the other hand, the recommendations of "The Six Committees," as the Commission notes in its report, can be carried out within the framework of existing legislation. These recommendations provide a procedure for placing in a deferred classification specialized personnel (Class II A). However, as the Commission remarks, there is a certain stigma associated with draft deferment of service age men: "The basic purpose of the Reserve is so to earmark specialized skills that a prestige will be accorded its members."

The endorsement of the earlier Committees' report, while proposing an alternative procedure for the utilization of engineering personnel, is confusing. Presumably the idea is to create the Reserve at a later date and depend for the time being upon the Selective Service Act as supplemented by the Committees' proposal to insure the best use of those possessing critical skills. On the dual assumption that (a) military and industrial requirements for engineering personnel are equally important, and (b), the present conditions of a mixed economy will exist for a long and indefinite period, the proposal for a Reserve may be the best ultimate solution.

The idea of a highly exclusive reserve with special privileges and prestige is, however, certain of political opposition and is not a complete answer for the manpower problems now facing those engaged in the defense effort. Industry is now losing engineering and associated personnel at a time when such defense agencies as the Research and Development Board are expanding existing programs and looking for new facilities. Engineers, scientists and other specialized personnel are already in "short supply" as well attested by the columns of help-wanted advertisements appearing in the newspapers of all major industrial cities. The situation calls for more immediate action than can be expected of Congress or the setting up of the involved deferment procedures proposed by The Six Committees. Accordingly, the proposal is here ventured that companies or divisions of companies now engaged in or committed to a significant degree to undertakings for the military be declared "Essential" and that their deferment problems be specially processed either within the Department of Defense under a directive from the Selective Service or by a special regional selective service board, depending upon the status—military or civilian—of the individuals involved. These special boards would be made up of persons who are at least broadly conversant with military needs and cleared to receive classified information of a kind that must necessarily be disclosed in making any claim for deferment of an individual on the basis of his group or company employment on essential undertakings for the military.

This suggestion is advanced primarily in the interest of conserving existing well-integrated working groups. Under this proposal, the deferment of an individual would not require that he be immediately engaged on a project of direct importance to the military. He would not necessarily have to rate either the designation of scientist or engineer. For special processing it would be sufficient that he be a member of an essential group.

Earl P. Stevenson

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Subject: "IMPROVING LIAISON BETWEEN RESEARCH AND ENGINEERING"

By: A.I.Ch.E. MEMBERS

Submitted to: EXECUTIVE DEPT.

Routing: ALL MANAGEMENT PERSONNEL

A Big Question today in the chemical field is how to improve and strengthen that important link between research and engineering: Between the men who discover a process and obtain the preliminary data—and the pragmatic engineers who must use the data and expand it to a going plant. Here members of the A.I.Ch.E. speak out their practices, ideas, and gripes. This article is the result of a "Bull Session" on the subject last year at our Swampscott meeting, plus editorial modification.

T. H. Chilton (DuPont Co., Wilmington, Del.): The topic, Liaison between Research and Engineering, illustrates the prime work of the chemical engineer, which, to my way of thinking, is to bridge the gap between chemical research and plant operation. The normal progression of research to operation includes such steps as determination, on semi-works scale, of the yield and quality of the products, obtaining data for the design of the full-scale unit, and naturally, producing some material for sales evaluation.

Then comes the stage of design, either of the pilot plant, the interim plant, or the full-scale plant, whichever is the next logical or justifiable step of the operation. This is the most critical stage, because at this point if you make a mistake, it is often frozen right into the process, frozen right into the design, and you may never get the opportunity again to correct it, because the demand for the product will keep you producing without giving you an opportunity to try out alternatives. When you get to the design point, obviously a few essentials are needed: the material balance flow sheet —that is axiomatic; the thermochemical data for a heat balance flow sheet; the critical pressures and temperatures, and compositions which become fixed points and are usually determined from the semi-works plant.

When these are known the detailed design of the pilot plant can proceed. It is here that the work of the chemical engineer is essential, and not much can be done to help him. He's out on his own and he has to make his own decisions.

He then builds the pilot unit with critical attention to every detail. Performance data are obtained and after a review of the pilot plant performance, the chemical engineer repeats the design procedure for the selection of the full-scale plant assembly and equipment. These may be merely a reduplication of the pilot plant units, or a scale-up may again be involved.

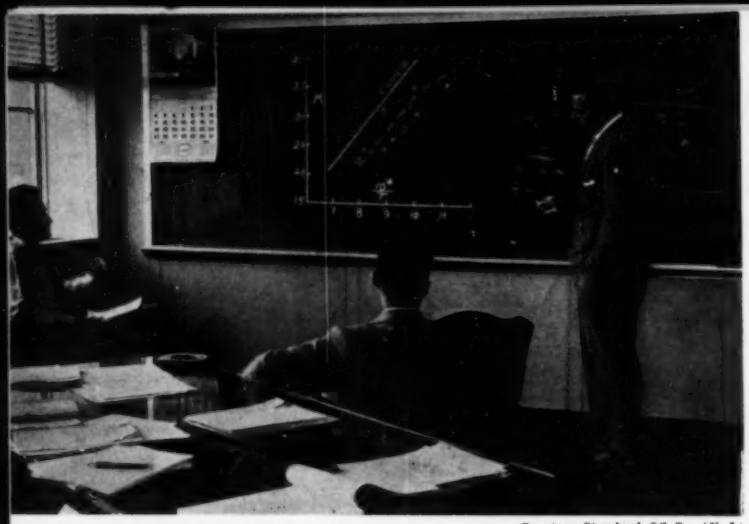
The liaison between research and engineering—we are talking about chemical research—involves four or five steps. They are first, a review of the chemical data with the research chemist on the part of the engineer; second, a check on the semi-works program and a review of the semi-works performance data; third, a process flow sheet and again, at this point, a check of that flow sheet with the operating people. Repeating: check the design of pilot plant equipment with the chemist first and the operating supervision; review the pilot plant performance after it has come through its stages of development with the chemist and with the operating management; finally, check the design of the plant with the chemist incidentally, but in great detail with the operating management. These are the stages, in my opinion, that the liaison between chemical research and engineering must provide.

Randolph Antonsen (Godfrey L. Cabot, Inc., Boston, Mass.): Almost every group has its own engineering setup and the ones I have known differed widely. The ideal setup would be to have chemical engineers who know the work—one man who could do all projects—to take a project as delivered to the chemical engineering group, and follow it all the way through. In other words, I'd rather have one man do all the work. If the company is large enough, a task will be turned over to several men, and each will follow his specialty through. But I think one man is needed who follows the work and pushes it through more or less as an expediter.

T. H. Chilton: I see what you are driving at: that it is better to have one man or a group of men who specialize carry the projects through as they come along. What we are talking about is the function of the group or individual that carries projects (as they come from the research chemists) on through design work. Perhaps there are firms where it is possible for one man to carry a project right on through, but that is asking a good deal of anybody—to do the chemical research, process development, pilot plant design and full-scale plant design. At some place you are going to break off from one type of specialization to another.

The type of specialization we are talking about is the transition, or the intermediate stage between operation or between the final construction of a plant and chemical research. There are gradations between those two. We are concerned with bridging the gap between the chemists and the design engineers. The question is whether the chemist can dissociate himself from it. Who will defend the process of having the chemist turn things over to the chemical engineer?

R. Antonsen: In some companies chemists follow through on the research work, in a personal sense, and participate and cooperate with the engineering development group. In other companies, though, the chemist will serve primarily



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". . . Once the preliminary work . . . has shown promise . . . a meeting is held for planning the program. . . . A program of pilot runs is laid out with the chemists pointing out critical process variables and the most favorable reaction conditions, and the engineers suggesting types of equipment, unit capacity and equipment layout. . . ."

in a consulting capacity between engineering and development groups.

T. H. Chilton: How can responsibility be assigned to these jobs?

R. M. Pritchett (Celanese Corporation of America, Clarkwood, Tex.): We have a research director who happens to be an engineer. Immediately under him in the research and development department are a chief chemist and a senior chemical engineer. Once the preliminary work of the chemists has shown that a particular project has promise, and when management has authorized more extensive investigation, a meeting is held for the purpose of planning the program. Those usually present will be the research director, the chief chemist, the senior chemical engineer, the chemist or chemists connected with the project, and one or more engineers assigned to the piloting and development. Usually the engineer has already had some contact with the project through preparing preliminary economic studies.

The work already completed is reviewed, and suggestions may be made at this stage as to further laboratory data needed by the engineer for use in pilot plant design. A program of pilot runs is then laid out, the chemists pointing out critical process variables and the most favorable reaction conditions, and the engineers suggesting types of equipment, unit capacity, and equipment layout.

After this meeting the project engineer draws a flow sheet of the proposed unit and, after further consultation with the chemist, prepares for approval a definite program of experiments. After approval, the engineer is then responsible for planning and evaluating the pilot work, while the chemist returns to the laboratory to continue his own program of experiments, which are usually not yet finished at this stage. During operation of the pilot plant the engineer often suggests further laboratory work to the chemist involved, while the chemist in turn acts as consultant to the engineer and informs him of any significant new laboratory results.

Formal responsibility for the pilot plant rests with the engineer. The same engineer, who may have the help of others if the process is of some complexity, continues to be responsible for any further development, including a final economic evaluation and the final process design for a commercial unit. This final design is turned over to the engineering department for shop drawings and detailed cost estimates.

Upon completion of the commercial unit, the same engineer, whose duties include both development work and plant process engineering, continues to follow the process until it is in smooth operation.

We thus have one engineer, or group of engineers, to carry the project through from the first laboratory development and economic evaluation to successful operation in the plant. It is the engineer's responsibility, through frequent contacts with the research chemist, to make sure that development is carried out in accordance with the basic principles laid down by the chemist. The chemist as a general rule is not directly concerned with plant design and initial operation, although during the entire development the project engineer regularly consults with him.

Norman Morash (American Cyanamid Co., Bound Brook, N. J.): We have a unique setup wherein an engineer may be responsible for an entire project from the inception of the idea to the point where the full-scale plant is turned over to the production department for routine operation. This has included the research work; the prepilot plant design, construction and operation; the pilot plant design, construction and operation; and full-scale plant design, construction and operation with economic appraisals interspersed at appropriate times. The engineer responsible for this work is called a special project engineer, who does not necessarily handle the research portion but who may on occasion.

We have also a standard routine whereby a product of the research department is turned over to the development department, whose personnel, with the cooperation of the chemical engineering and plant engineering departments, through the direction of a technical committee, carry the product along until a full-scale plant is built and turned over to the production department for operation.

This standard method, however, has two distinct drawbacks. One is communication and the other, time consumed between the conception of the idea and the birth of the plant. Anyone who has written a final report on a research project or a set of specifications on a new plant, knows how easy it is to leave out items. By the time a project has passed through several hands, many points are bound to be forgotten or omitted and hence, the final plant must suffer. The other point is that with many groups involved, time is lost in committee meetings and in making decisions. Also if no one person has the authority or interest to push the job it does not get done.

On certain projects perhaps three or four years could be spent from the initial research stage to full-scale plant operation. When a job is run by a special project engineer, this time may be cut in half.

John A. Brooks (Standard Oil Company of Ind., Whiting, Ind.): How can you define the responsibility for this one man to carry the project straight through?

N. Morash: He is completely responsible for the entire project. It takes a man of a few years' experience, but on the other hand, it is set up so that it can be carried through. But I will say that in most cases the jobs are primarily engineering and there isn't too much high-powered chemistry. There is some chemistry, but it is mainly a chemical engineering job.

J. A. Brooks: I would like to know about the economics involved. Suppose a problem gets on the way, and this proj-

ect engineer has been working on it for awhile. Who is going to decide, when you get about half-way through, that it is feasible economically? Is that his responsibility?

N. Morash: The special project engineer must keep his economic evaluations up to date as the project progresses, and should any development alter the picture, it is his responsibility immediately to inform the management committee. At such a time a decision is made to discontinue, maintain, or to accelerate the job.

J. A. Brooks: Sometimes these economic evaluations take a long time, and a large staff is required. How do you handle that?

N. Morash: This is also his responsibility. It should be understood that the special project engineer does not have to work singlehandedly. At times it is necessary for him to have 50 to 100 people directly or indirectly under his control. There are also times when, due to the nature of the project or the state of development, he may be the only one active on the project. It is believed that due to this flexibility of operation no project need be too large or too small for him to handle and a multimillion-dollar project can be carried out just as effectively as a ten-thousand dollar one. Furthermore, the size of the company or plant does not need to have any effect on the efficiency of such an operation.

John W. Payne (Socony-Vacuum Oil Co., Inc., Paulsboro, N. J.): In some companies as soon as a project begins to look attractive to the research chemists, the economics section of the development division takes a look at it. If it is sufficiently promising, the development division starts an appraisal. This often leads to something like this: the research chemists are asked to do additional experiments to provide information necessary for a better economic evaluation and to indicate the best type of pilot plant to be set up. Often the chemists do not quite appreciate what goes into the engineering development of a project, hence the necessity of the additional experiments. As soon as the development division gets the additional information, the economics section makes a critical appraisal of the project. If the project still looks attractive, a pilot plant is laid out and built. By the time the pilot plant has been running a few weeks or a few months, they are in a position to tell whether the project is going to be attractive commercially.

Now the actual contact between the chemists and the development engineers is that the chemists follow along in the early development stages and get the data necessary for designing the pilot plant, and at the same time they also continue to develop basic information which is used as we go along with the pilot plant development.

Of course, all have a keen curiosity in the results, and exchange ideas and information all during the development, to keep in touch with the latest basic ideas and latest pilot plant results.

T. H. Chilton: Who takes the responsibility for the decisions to develop the project?

J. W. Payne: The economics section determines whether or not the project is attractive on the basis of the information available at the time. Management makes the decisions.

T. H. Chilton: Who authorizes the money that is required to carry through to the next stage?

J. W. Payne: The development division, of which the economics section is a part, issues a letter or memo to the director to the effect that the project appears attractive. He presents the proposition, with the accompanying economic picture, to the manufacturing committee and asks for an authorization to go ahead with the pilot plant.

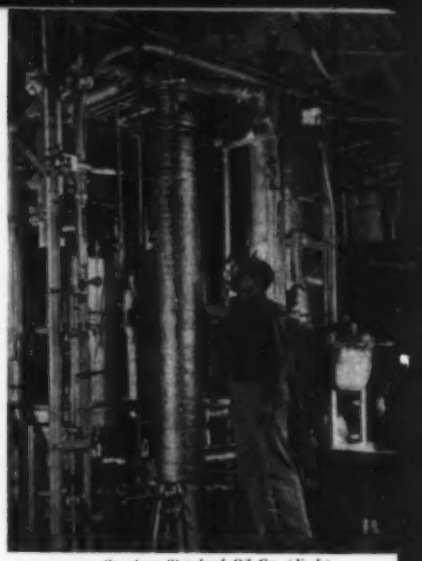
R. G. Edmonds (Carbide and Carbon Chemicals Corp., S. Charleston, W. Va.): What does the time schedule add up to?

J. W. Payne: The time required for the development frequently is annoyingly long. The time for the authorization is usually a few days to a few weeks.

A. T. Osserman (Davison Chemical Corp., Baltimore, Md.): You mentioned the economic section. When does that take over? Does it take over when the research chemists initiate the project?

J. W. Payne: The economics section never actually takes over. The project is brought by the research chemist to the economics section for its appraisal as soon as it appears attractive to it. An evaluation is made and desirable additional experiments are suggested. This type of contact is maintained throughout the development of the project, by which the economics section establishes whatever phases of the development offer most promise of improved commercial economies.

Anonymous: We started out talking about liaison between research and engineering, and as I understand it, it is a transition from the conception of an idea to the point when it is in full production and making money. Apparently there is good liaison between research and engineering, otherwise so many new projects would not be developed, and so many new products would not be getting to the market. We might wonder where this liaison takes place and we would no doubt appreciate it if it worked out at a lower level. Apparently it is up at management levels. It might be a good scheme to have a special project engineer follow projects from the laboratory bench all the way through to the time



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". . . The normal progression of research to operation includes . . . determination on semi-works scale, of the yield quality of the products, obtaining data for the design of the full-scale unit, and naturally, producing some material for sales evaluation. . . ."

when the plant goes into operation. Now this might be feasible in projects that are simple, and which involve only one or two steps, and not great outlays of money or of engineering thinking. Chemical engineering is becoming more and more a specialization. A man so versatile as to be able to handle all phases of engineering from development to final pilot plant design, and at the same time have a personality which is such that he can get along with the research chemist, is being wasted as a project engineer. Undoubtedly he should be vice-president of the company.

Liaison in most organizations is carried out at upper levels of management. The latter will decide on a particular field of endeavor, will instruct the research chemist to work on a specific problem. When that end has been solved, the brain child generally goes to a development chemist who irons out the kinks in it, then to the development engineers who look at it from an engineering viewpoint to see if it is going to be feasible or whether the process will have to go back to the development chemist and have him change the solvent, or the temperature or pressure conditions, so equipment currently available will more or less fit the project.

When this work has been ironed out there is a pretty good level of liaison with management. The latter decides then, after an economic study is made, whether it is willing to invest its dollars and cents in the project, or whether it has seen enough of it so that it is not

willing to go ahead. Unless a chemical engineer is part of management, he doesn't have anything to say in this matter one way or the other.

After that point a pilot plant generally is designed to justify the expenditure of larger funds. The so-called engineering divisions are brought in, and they use the data developed by the development engineers, pilot plant engineers, development chemists. By this time the original pure research chemist who dreamed up the scheme is so far back in the picture his name is not even remembered.

As chemical engineers below management level, sometimes we do not see the connection between what we are doing on a job and what the other divisions of the organization are doing, and we would like to have closer liaison. Perhaps the reason we don't have it is because we do not get together with them often, or perhaps we are physically separated from them so we cannot get together. It has been my experience that the liaison is there. Otherwise chemical engineering would not have reached its present state.

W. L. Faith (Corn Products Refining Co., Argo, Ill.): I haven't any problem as far as transferring material from research to engineering is concerned. There is a problem in another way—getting back into research early enough to get the chemist to do the work with some engineering sense.

You get project after project coming through where a chemist uses a Waring blender—but try to put a Waring blender on a big scale. There are things of that sort. A lot of time could be saved if some of the tools which are used in research were not used, or if other tools were used which were easier to extrapolate.

T. H. Chilton: That is certainly one aspect of the problem, namely, to get the engineering viewpoint carried into the research at an early enough stage so that the proposal for a manufacturing operation bears some resemblance to what can feasibly be designed and carried out.

Max Potash (American Polymer Corp., Peabody, Mass.): Undoubtedly, quite a bit of futile research work might be avoided or diverted into more promising channels if the large-scale feasibility from an engineering viewpoint was evaluated in the early stages. However, excesses in this direction may be harmful. The chemist should not work in an ivory tower, oblivious to practical considerations in commercially applying his work, but the engineer should not have too dogmatic or inflexible an approach. There have been many cases in which the chemical development was novel and apparently severe engineering difficulties could be anticipated, but new techniques and equipment were devised to meet the challenge and successful operations resulted. To have suppressed the chemical inventiveness until the engineering know-how was also available would have impeded progress. The research chemist's position should not be usurped and he should not be unconditionally restrained from exploring new fields because large-scale adaptation seems to involve difficulties.

Anonymous: I'd like to say it the other way around—it is not always the research chemist's fault. I find the chemical engineer is greatly responsible by not using his own knowledge of chemistry or chemical engineering to understand a chemist. He likes to have the research chemist dish out all the data when he could easily take out a slide rule or a handbook and get it himself. Frequently the research department will give you a set of data, and if something is missing, the chemical engineer could extrapolate that data himself. Liaison should work both ways. If we have gripes, I know the research chemist has many justifiable gripes about us. We should rely more on the fundamentals of chemical engineering to interpret research data, rather than to have everything ironed out for us. By making our own analysis we can often suggest better conditions without doing any pilot plant work or any additional research work—just by using thermodynamics, mass action, etc. You can predict just what would be the best way of doing it in terms of equipment which is either established in design or that you could design and have made through. We should put ourselves in a position whereby we could understand more and be patient with the chemist just as he is with us.

F. L. Matthews (Monsanto Chemical Co., Everett, Mass.): I don't think we are talking about liaison at all. We are talking about a deficiency among chemical engineers—a deficiency in chemical engineers in making clear and in helping in the training of industrial chemists.

First, in our research group we have a lot of chemical engineers, but all our chemical engineers are not confined to research work. Sometimes our chemists have considerably more experience than some of the chemical engineers. I think we are really talking about the gap in the transfer of knowledge from one group to another.

T. H. Chilton: Exactly, and we are trying to find more effective ways of bridging that gap.

F. L. Matthews: That is a good objective, but how can it best be accomplished? Perhaps discussions like this with a larger representation of research people would be in order.

T. H. Chilton: There is a responsibility here that you can't expect the research chemist himself to fulfill. Somebody has got to carry it through. His forte is chemical research and he can be expected to bring in new ideas, but somebody has to translate them into practice. Maybe he can, but then he is getting outside of his most effective area.

F. L. Matthews: Isn't that making a distinction between engineering research and fundamental chemical research

Courtesy Standard Oil Co. (N. J.)

". . . The chemical engineer repeats the design procedure for the selection of the full-scale plant assembly and equipment . . . checks the design of the plant . . . in great detail with the operating management. . . ."

rather than industrial chemical research? I don't think an industrial chemist functions efficiently unless he has acquired considerable experience with engineering problems. The closer he ties in with design engineers, the better.

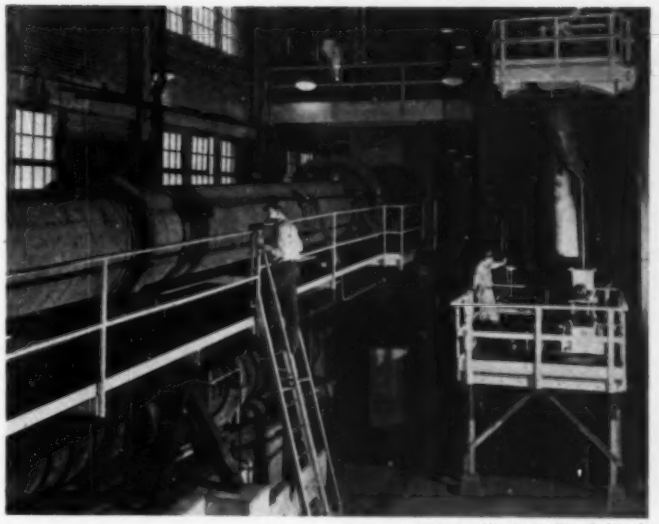
The chemist will say the engineer is trying to direct his research. If you approach it in that manner, it is an insoluble problem because you are trying to decide who predominates. Rather than that unending argument, let's try to find points of agreement and expand from there and try to find the points of disagreement.

W. F. Stark (Davison Chemical Co., Baltimore, Md.): Isn't it part of the problem that there is so much absorption in day-to-day jobs that the components of the whole team, the fundamental research men, the engineers, the economic research men, do not understand one another's language and problems any more? If we are so specialized that we do not understand one another's problems, and if we don't have the understanding ourselves, I don't see how any kind of management or procedure is going to bridge the gap. Perhaps specialization can be carried a little far.

T. H. Chilton: We must have a certain amount of specialization—that is the origin of our problem.

W. F. Bixby (B. F. Goodrich Chemical Co., Cleveland, O.): We at Goodrich have a solution that has worked nicely for us on liaison between research and development engineering. We have two groups—a research group—I am using research in the broad sense to include pilot plant investigations—whose duty it is to define the conditions of a new process, and a development engineering group whose responsibility it is to design production equipment for the new process.

Some years ago we became aware that our research people had a tendency to carry out their investigations along lines of endeavor which were not always easily translatable to full-scale production equipment. In order to improve this condition, we selected a man with experience in production, in engineering design, and in engineering development. This man was placed in a research group to guide its personnel in their endeavors. He is there now primarily as a consultant. He can serve several units which are working on different full-scale research projects. As each unit develops its process it avails itself of his experience and knowledge to guide its efforts toward the realization of a practical production method. It tells him what it basically wants to do and asks him what unit operations are available, what sort of equipment is practical and obtains any other suggestions which he may be able to offer toward the achievement of a practical method. If this engineering consultant is confronted with problems which he feels inadequate to handle personally, he can—and does—enlist the aid of the development engineering group which is composed of men with collectively a greater range of experience in chemical engineering design. Having thus fortified his own ideas, he can relay the information back to the research investigations. With this sort of relationship, we have been able to work out an effective connection between the research and development engineering groups which aids substantially in achieving basically sound and efficient production methods for carrying out new chemical processes.



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". . . When you get to the design point, . . . a few essentials are needed: the material balance flow sheet; thermochemical data for a heat balance . . . critical pressures and temperatures and composition which become fixed points and are usually determined from the semi-works scale. . . ."

W. S. Coe (U. S. Rubber Co., Naugatuck, Conn.): I wonder if a little better definition of terms wouldn't be in order. All of us have different kinds of products and different types of organizations. It may well be that one type of organization will work well in an oil company and another in a chemical company.

Taking research, for a moment, I'd like to think of research as the originator of the new product. A new product may be produced in test-tube or in laboratory quantities. My conception is that the research group should not worry about the process by which that material will be made commercially. The process work should then be passed on to the process development group. I think a process development group should have a process research unit who should specialize in taking a product that the research group has discovered and developing the best process. We are talking now about process research composed usually of organic chemists or research caliber people. Chemical engineers working closely with process research people will find them practical-minded, and anxious to develop the data necessary for design. They understand the problem and the close relationship with pilot plant work, and I think this approach clears up the difficulty that several people have mentioned—that of going back to an academic-minded research man and getting the sort of data needed for design data. Research men should spend their time making up new materials to keep new products coming along. They should not be worrying about processes. The process research group is the answer to most problems we are talking about.

T. H. Chilton: Certainly that is one answer, but the research we are talking about is the bench-scale chemical research that generates a small dream of a new product.

R. Antonsen: We are getting to the point now where it is a question of the size of the company. In a small company, one man can work between the two. In one case previously discussed, there was a small research group and a small process design group. One man could work between the two. In this latter case where you have a much larger organization, a man could be assigned to a development group. I don't know how you could discuss this without considering the size of the company. In all the discussion so far, we missed some

points because some have been talking about small companies, and others have been talking about large companies.

T. H. Chilton: Unfortunately that is the case. What I'd like us to describe is the function and how that function is best fulfilled.

Anonymous: I want to expand on Antonsen's remarks on the differences between organizations. Depending upon size an organization develops a way to handle any particular project. To expand that further, we should have a clearer definition of our terms. We speak of research, and so far it has been defined as a pure researcher, who conceived the idea and also as the fellow who worked out conditions in the project. Somewhere along this line you must confine yourself, when you speak of research, to a man who conceived the idea, and then I agree with the remarks as made.

The men who do pure research should, when they have conceived an idea, go on to further fields, and turn the idea over to somebody more capable of developing ideas that have already been conceived.

We should try to define our terms before trying to evaluate how liaison is to be done. In most cases, pure research can be done in a university, but you don't invite the professor out to the plant though you might invite him over to see the plant when it is finished. Generally it is the development chemists who take that process and go to the development laboratory and iron out the kinks.

O. C. Jones (Monsanto Chemical Co., Seattle, Wash.): The one problem I have heard here is to get the chemist to speak the chemical engineer's language, and that is the process of teaching. Both use strange terms. I have a feeling that a dipole moment to an engineer has no more meaning that a heat-transfer coefficient to a chemist. We are speaking of educating a chemist to the engineer's terminology. Further, we are speaking of putting the chemical engineer to work on a bench with the chemist, or as another speaker said, of sending the chemical engineer back to operate the chemist's equipment in the laboratory. This is something that is not a question of the size of the organization. It is a problem only of communication. I think there is some need to educate the chemist in the chemical engineering terms. I have a feeling that the chemist's idea of learning a chemical process is to learn the chemical equations that cover it, without any thought of the engineering problems. Those who spoke of solving the problems have done so by educating the chemist in the engineer's terms. That might be formalized. You might have the design group come down to the research lab. and tell the chemists of the engineer's problems. Let your chemist meet the chemical engineer. Just as the chemical engineer can see ways to explain to the chemist the methods and tools he can use in development, so the chemist can explain his limitations to the chemical engineer.

T. H. Chilton: Improvement in the art of communication is desirable in any situation but I think there is a real problem here and that is doing the job most people do not expect the research chemist to do; namely, to design the plant. How to translate the requirements of the chemical process to lines on the drawing is a large problem that isn't solved merely by a definition of terms.

Fred C. Mitchell (Du Pont Co., Wilmington, Del.): There have been several discussions on the size of the organization and it enters into the question considerably. I think it's comparable to the medical profession. If you are in a small community, what you need is a good diagnostician. You don't need heart or brain specialists. In a community of three million, however, you can use a lot of specialists.

A small organization can't have a group of experts in chemical engineering and separately in chemical research. One man has really to fill the job; the company needs a good diagnostician. I think in terms of one man who has filled the bill in that order on a grand scale, and that is Clifford Seidel who has done the main research work and development operation on helium production. He worked on helium research, did the development work in the research lab., and later on headed up the engineering work. He is now, I believe, running the Bureau of Mines helium production unit. But that is a small organization. I don't suppose there are more than 100 men in the organization including production. If you go from that to a large organization, you come into a different picture. In a large corporation we just have to stop the question of the chemist, the chemical engineer or whoever it is, getting the credit. The main problem is to get the price down and the products on the market. Whoever can do that job ought to do it.

The opinion has been expressed that there is an opportunity for a man to be assigned to the work as the chemist develops the problem in the laboratory, to dispense engineering experience. He can't be a man a few years out of school; he needs a wealth of varied experience. He doesn't have to sit down and take a slide rule and solve the problems as long as he knows who has the answer. As I mentioned in medicine—the diagnostician does not have to be an expert in heart disease, he doesn't have to be a surgeon, but he does have to know from whom the answer is obtainable. I think that is the way we can analyze this problem for the larger chemical organizations.

Robert L. Stern (Stauffer Chemical Co., Chauncey, N. Y.): I'd like to report on a method which we have tried in our organization that has effected liaison successfully. We run a small research group and at times are faced with the problem of introducing a chemical invention or process to the engineering or production departments. At that time we form a task force consisting of a few men, qualified, by their diverse experience and broad education in chemistry, chemical engineering, economic analysis, production and personnel methods, to form this most direct link between research and engineering. The task force is directed against one particular problem, operates under the supervision and guidance of the director of research, and follows the research idea from the laboratory to its final execution. It represents our liaison from laboratory to plant.

N. Morash: I'd like to discuss the way a project engineer can get a job done. By the time you have carried a project through research chemist, process development chemist, process development engineer, chemical engineer, plant engineer, and finally into production, you have gone through so many people that many important items are left out and all liaison has long since been lost.

If you put in charge of an operation a project engineer who is responsible for that job, after it is conceived by the research department, and give him the full responsibility for getting the job done, he can follow it through in the quickest time. If you have to wait for meetings between your various groups and shift responsibilities time is wasted. A competent engineer in charge of the operation will save time and eliminate headaches. He may consult a specialist when he needs to, but even so, he is still in charge, and he gets it done.

Anonymous: This policy of letting an engineer follow something in research through design sounds attractive, but I wonder where all these competent project engineers come from. One out of seven research ideas pan out. Now if you are going to have a project engineer follow each of these through, that means you'll have to have seven times as many project engineers as are now available. Where are they coming from?

R. G. Edmonds: In this connection, it is easy to delay a good project by spreading manpower too thin. There are so many ideas coming through in a large organization that I do not see any possibility of using the project engineer idea. Somewhere along the line proposals have to be sifted and considered. I have found that one thing which helps is to do the same thing for research and development chemists as is done for man-

agement. We prepare carefully considered summaries from an economic and engineering viewpoint of the value of the process, of the products, and the value of the extent of engineering development required. We weigh the process in terms of money, policy, and products that we are making; also in terms of any experience we have had or can scrape up. Frequently all this has not been passed back to our research and other interested development men. We find a most valuable supplement; for every ten hours spent in summary preparation another hour is devoted to assisting management and research in the digestion of this information. Liaison at this stage does not appear particularly important to the chemist, but for his real enlightenment, just chalk up on a board the relative costs of process equipment.

We have been considering the use of a fluidized reaction system and have encountered the usual troubles experienced by pilot and development groups. So much attention has been concentrated on this portion of the process that the other more conventional equipment is accepted as secondary. Actually when we start to itemize the entire plant, it turns out that only 12 per cent comprise the reaction system. The proper sense of proportion is restored by the fact that we could pass back this viewpoint and could point out the many other problems of cost and design which must be considered. This helps immeasurably in securing cooperation. Process details may not be remembered, but these men do remember the consideration you have given them.

J. C. Lawrence (Du Pont Co., Wilmington, Del.): This is a discussion on liaison between research and engineering. What we are talking about are personalities, or personnel, because engineers can get along with research men, beautifully. With little effort there is no trouble. If you visit around with the fellows who are developing a process, you get along all right. I think chemical engineers are doing it. I think if we didn't we wouldn't have organizations.

E. G. Somogyi (Monsanto Chemical Co., Springfield, Mass.): I want to say that there can be too much liaison. I have had some experience, and I'll give two examples: One is the case of the engineer in on a project so early that he formed his notions, and ignored all subsequent developments in the research department. He did too much of his design on preliminary work. He had a fixed idea and it was rather hard to sway him.

An example in the other direction was of a research man who was so familiar with the limitations of certain pieces of equipment that he conditioned his thinking and development, and limited himself seriously. If the research man is made to hold the mixing to that which we can get on a 2000-gal. glass unit, he is likely to give up if he can't get the agitation he wants for his experimental work.

R. M. McAdam (Du Pont Co., Wilmington, Del.): There are two schools of thought here; one has a problem, the other doesn't. If the research chemists and the chemical engineers meet only through the medium of the "final" written report of the chemist, you have a problem. Most research directors feel the need of chemical engineering guidance during their work, and have chemical engineers on their research staffs. Liaison is effected from the beginning of any project. The chemist gains through this contact and will be more valuable in later work if he is allowed to follow at least one project through economic evaluation, design and plant start-up.

There may be some lost motion in early training, but it will show up in later results. I am from the school that believes if you start your liaison from the beginning, you do not have a problem.

Anonymous: It seems to me that the chemical engineers and chemists do not speak the same language. I remember a case where a process went to the pilot plant for operation. The first batch was made, the engineer in charge called on the chemist and asked, "How did you get that stuff out of your beaker in the laboratory?" "Why," said the chemist, "I just took a spatula and scraped it out." "Come on out," said the engineer, "I have 200 gals. of it."

They may have slipped up in letting that get through, but the chemist had no concept of what he was doing when he made up the process. However, you may find an engineer, ready to do some designing, saying, "I have to get this heat of vaporization—nothing can be done until I do." So it has to be determined.

You have seen a chemical engineer come into the lab. and try to do it himself. He then appreciates what a problem it is to determine these things in the laboratory. What we need is education on both sides of the fence. The chemical engineer should know how things are done in the laboratory. The chemist in turn ought to know how things are done in the plant.

I propose that we educate young engineers. A chemical engineer should work in a laboratory and it would be a good idea if the chemist went into the plant so he, too, can appreciate other problems.

Austin W. Fisher, Jr. (Arthur D. Little, Inc., Cambridge, Mass.): It seems to me that in trying to get together on a general conclusion, we are really on the wrong track. We all have different problems and every company has a different set of personalities to work with and a separate set of processes and products. We shouldn't try to agree on an answer that suits all of us. We oversimplified

Courtesy Celanese Corp. of America

". . . It all depends on the size of the process or project how the chemist stays in the picture, either full time or as a consultant—perhaps as a key member of the team. . . ."

and began by talking about the idea at the lab. and carried on through. It isn't that easy. Originating the idea involves quite a bit of the work, and I can't see where the engineer fits in until the chemist has the idea and takes the first crack at it. But right there, the engineer should first become involved, although primarily as an adviser.

One system that seems to me quite workable puts it squarely up to the man in charge of the over-all research and development. After the chemist produces something, then it should be turned over to an engineer or several engineers for evaluation. After the economic picture has been established roughly, it might prove advantageous to sit down with the chemist, go over it again, and say that the thing doesn't look so hot from a commercial standpoint—too expensive to do it this way—or we will need these data here, or these other points on this phase. Then, if it looks at all feasible, the chemist finishes his job—which may take some time during which the engineer is out of the picture. If after that, the thing still looks satisfactory, then the project engineer should take over, because from there on it becomes engineering. It all depends on the size of the process or project how the chemist stays in the picture, either full time or as a consultant—perhaps as a key member of the team and perhaps just to sort of follow along to see how his brain child is coming along. Trying to generalize beyond that for a group conclusion is getting too specific.

(The End)

RATE OF GROWTH OF CRYSTALS IN AQUEOUS SOLUTIONS*

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It has been found that r_g, the rate at which copper sulfate pentahydrate crystals grow in an agitated solution at constant supersaturation, may be expressed in terms of the relative velocity between crystals and solution, u, the interfacial growth rate, r_i, and the growth rate at zero velocity, r_o, by the empirical equation

$$\frac{1}{r_g} = \frac{1}{r_o + \beta u} + \frac{1}{r_i}$$

The growth rate is not affected directly by crystal size, but, at low values of u, r_g is markedly influenced by the crystal-solution velocity. As u increases the effect of velocity on growth rate diminishes and finally becomes negligibly small. These results are consistent with the view that the growth process consists of a mass-transfer process from the solution to the crystal surface followed by a reaction at the interface which is as yet not fully understood.

In a crystallizer in which the crystals are maintained in suspension by means of an agitator, large crystals grow faster than smaller ones because the larger crystals benefit from a higher relative velocity with respect to the solution than do smaller crystals, and the relative velocities in both cases are in the low range.

LOGICALLY the crystallization process is divided into two steps—the formation of crystals and their subsequent growth. This paper is concerned with the second of these two steps—the growth process; it constitutes an attempt to obtain answers to these two questions:

1. Does the size of a crystal affect its linear rate of growth, and, if so, through what mechanism?
2. How is the rate at which a crystal grows affected by the relative velocity between the crystal and the solution in which it is growing?

Some preliminary information was obtained also on the effect of supersaturation on rate of growth.

* The original manuscript in extended form is on file (Document 3141) with the American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Microfilm obtainable by remitting $1.00 and photocopies $8.70.

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Literature Review

The literature on crystallization is voluminous and only those investigations concerned with crystal geometry and with the theories and kinetics of crystal growth are cited here. With respect to crystal geometry the work of Gibbs (*5*), Curie (*4*), Wulff (*20*), Berthoud (*2*), and Valeton (*16*) is of fundamental importance. Valuable contributions to the development of a quantitative understanding of crystal growth have been made by Noyes and Whitney (*14*), Bruner (*3*), Nernst (*13*), Marc (*8*), Wagner (*19*), Berthoud (*2*), Valeton (*16*), Kucharenko (*7*), and Van Hook (*17*). In recent years the work of Volmer (*18*), Stranski (*15*), Becker (*1*), and their collaborators has led to important progress in the development of a physical theory of crystal formation and growth. Mehl and Jetter (*11*) and McCabe (*10*) have reviewed these recent contributions.

A review of this literature reveals that the process of crystallization from solutions involves both mass transfer from the solution to the crystal face and an interfacial reaction which is related to the work required to add a new lattice plane to an already formed crystal. No completely satisfactory expression for the rate of crystallization from solutions has been developed. Although it is known that the rate of crystal growth increases with agitation and with temperature, few attempts have been made to evaluate quantitatively the effect of these variables. Some data are available to substantiate at least partially the postulate that in crystallization from a melt the liquid to solid transition proceeds through an activated state requiring a definite activation energy.

The shape of a crystal existing in exact thermodynamic equilibrium with its saturated solution can be defined in terms of the specific free surface energies of the various faces, but a growing crystal does not necessarily adopt the equilibrium form. The relative development of the individual faces of a crystal may be altered radically by impurities in the solution and perhaps to some extent by growth conditions.

McCabe (*9*) developed a method of predicting the size distribution of the product of a crystallization process from the size distribution of the seed crystals and verified the theory experimentally for relatively small amounts of crystal growths.

Experimental

In the present work crystal growth was first studied by growing seed crystals in an agitated solution cooled at a controlled rate. Results obtained from these experiments, although somewhat inconclusive, led to a study of the effect of crystal size and of relative velocity between crystal and solution on the rate of growth under conditions of constant supersaturation and temperature.

Rate of Growth of Crystals in a Stirred Seeded Solution. In this section a seeded solution was cooled from its saturation point to various lower temperatures and the distribution of the solute on the seed crystals was determined at the end of the growth period. Conditions were so chosen that no appreciable formation of new crystals occurred.

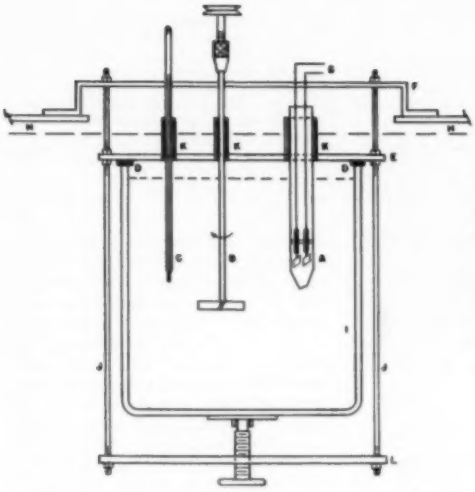

Fig. 1. Sketch of crystallizing unit.

A. conductivity cell
B. stirrer
C. thermometer
D. rubber gasket
E. cover plate
F. supporting bracket
G. leads to bridge
H. water bath cover
I. crystallizer jar
J. tie rods
K. copper tubes
L. retainer plate

Apparatus and Procedure. The small batch crystallizer (Fig. 1) which was used, consisted of a cylindrical, flat-bottomed glass jar, I, of about 1200-cc. capacity mounted between a brass cover plate, E, on top and a retainer plate, L, below and held in place by brass tie rods, J, between the two plates. The crystallizer was fitted with a four-bladed glass stirrer, B, driven by a variable-speed motor; a 50° C. thermometer, C; and a conductivity cell, A, which is described later. A hand-screw arrangement at the bottom allowed the retainer plate to be released quickly, and permitted prompt removal of the crystallizer jar from the assembly. The crystallizer was mounted in a water bath, H, through which water at a controlled temperature could be circulated and the rate of a cooling of the crystallizer charge thereby controlled.

During operation the crystallizer unit containing 1000 g. of a solution of copper sulfate saturated at 28° C. was completely submerged in the water bath. The desired rate of cooling and speed of stirring were established and when the solution reached the saturation temperature, the seed crystals were introduced and, at 10-min. intervals thereafter, the time, the solution temperature and the Wheatstone bridge reading were recorded. At the end of the run, the crystals were separated from the mother liquor by filtering through the 200-mesh copper screen sealed into a Gooch crucible. The crystals were washed with alcohol and acetone, both saturated with copper sulfate and weighed.

To follow the concentration history—and thus to determine the supersaturation of the solution during the crystallization process—a modified conductivity cell positioned in a Wheatstone bridge circuit was used. The cell (Fig. 2) was so designed that the platinum electrodes were shielded from the scouring action of the crystals in the solution.

To convert the measured resistances to corresponding concentrations, the conductivity cell was calibrated by measuring the resistances of copper sulfate solutions of known concentrations at various temperatures. The resistance-temperature relation was determined over a temperature range of 20° C. to 32° C. for saturated solutions and for solutions varying in concentration from 39.32 to 46.72 g. $CuSO_4 \cdot 5H_2O$/100 g. of "free" water. For convenience in plotting the resistance data obtained in the runs the calibration data have been plotted as resistance vs. concentration at constant temperature. Because of minor fluctuations in the cell constant from run to run, it was necessary to correct the measured resistances so that the concentration curve crossed the saturation curve at the saturation temperature.

Size Distribution Determinations. Crystal sizes were measured microscopically by means of a microprojector. The method, although tedious, is more accurate than measurements made through the use of sieves. To determine the size distribution of a batch of crystals by this method it is necessary to measure the individual crystals contained in a representative sample of the batch. A sample of the crystals, obtained by successive quartering, was evenly distributed on a microscopic slide, and using a millimeter scale graduated to 0.01 mm. or 10μ, the dimensions of two adjacent sizes of each crystal encountered in several traverses of the slide were measured. The square root of the product of the two dimensions was taken as the crystal size.

From the relation between the number of crystals of size L and the total number of crystals in a representative sample, the size distribution can be calculated in the following manner:

The mass of a polyhedron is

$$w = \rho b L^3 \tag{1}$$

If, in a batch of crystals of various sizes there are N_1 crystals of size L_1, N_2 of size L_2, etc., then the mass of the entire batch is

$$W = N_1\rho b_1 L_1^3 + N_2\rho b_2 L_2^3 + \ldots + N_i\rho b_i L_i^3 = \sum_{i=1}^{n} N_i\rho b_i L_i^3 \tag{2}$$

If the crystals which are measured (N_m, W_m) are representative of the entire batch, then

$$W_m/W = N_m/N$$

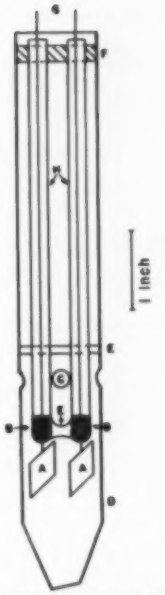

Fig. 2. Sketch of conductivity cell.

A. platinum electrodes
B. mercury contacts
C. ¼-in. holes
D. glass shield
E. glass seals
F. cork washer
G. copper wire leads
H. ¼-in. glass tubes

and

$$N = \frac{WN_m}{W_m} = \frac{WN_m}{\rho \sum_{i=1}^{n} (N_i b_i L_i^3)_m} \tag{3}$$

in which the quantity under the summation sign applies to crystals actually measured.

This equation relates the total number of crystals to the experimentally determined relationship between size and number of crystals. It is desirable to obtain the size distribution on a cumulative basis, i.e., to express N_c, the total number of crystals of size L or larger, in terms of $(Nm)_c$, the total number of crystals measured of size L or larger.

Since

$$\frac{N}{N_c} = \frac{N_m}{(N_m)_c}$$

Then

$$N_c = \frac{W(N_m)_c}{\rho \sum_{i=1}^{n} (N_i b_i L_i^3)_m} \tag{4}$$

It is assumed in the derivation of Equation (4) that the crystals measured constitute a truly representative sample of all the crystals in the batch.

All the quantities on the right-hand side of Equation (4) can be determined and therefore an actual cumulative size distribu-

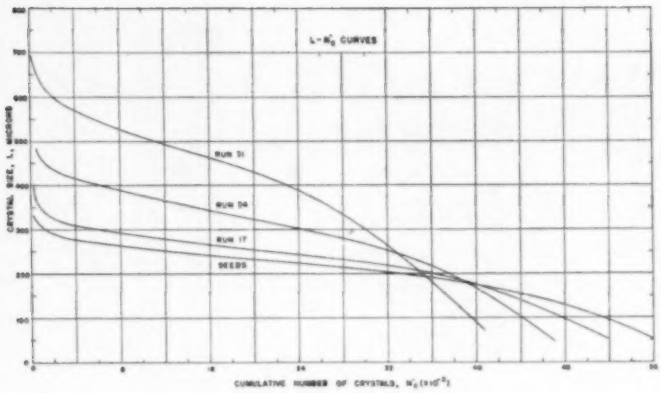

Fig. 3.

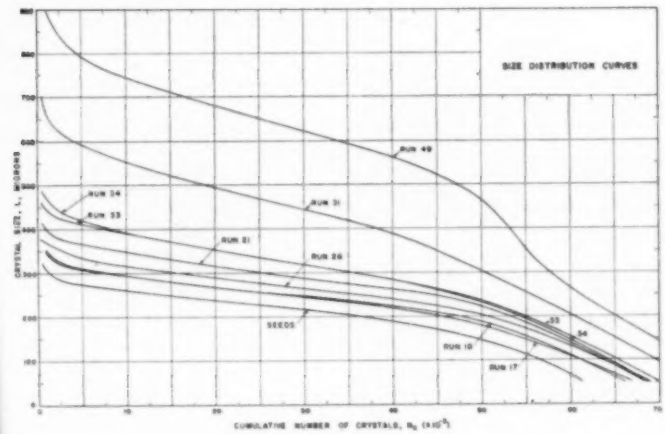

Fig. 4.

tion curve, i.e., a plot of L vs. N_c, can be obtained.

Determination of Shape Factor. The principle of invariancy of crystal shape which states that a crystal remains geometrically similar to its original shape as it grows under constant external conditions has commonly been assumed in studies of crystal growth. When growth occurs under variable imposed conditions, it is reasonable to expect that the shape factor will change. Nelson (*12*), in attempting to explain the deviations from the ΔL law which his data showed, suggested that the shape factor might change as the crystal size increased.

In order to determine the shape factor of crystals grown under the conditions used in the present investigation, selected crystals from the seeds and product of the runs described in the next section were weighed and measured and the shape factor calculated. Ten groups of reasonably perfect, uniformly sized crystals were measured. Nine of the determinations proved satisfactory. For convenience the shape factor is expressed in terms of crystal size; since crystals of the same size group were used in all runs, this appears justifiable. Since the two quantities ρ and b appear together, the product ρb has been calculated instead of the shape factor b.

ρb has been calculated from the relation

$$\rho b = \frac{W}{N(L_{av})^3} \tag{5}$$

Results of the measurements and calculations (Table 1) indicate that the shape factor decreases with increasing size and rapidly approaches a constant value at the higher crystal sizes used.

The effect of this variation in shape factor on the size distribution curves can best be seen by comparing the curves obtained when the shape factor was assumed constant with those obtained when this assumption was not made. For the former case an arbitrary cumulative number of crystals, N'_c, can be defined such that $N'_c = bN_c$. In Figure 3 the size distribution curves of the seeds and products of several runs discussed in the next section are plotted as crystal size, L, vs. this arbitrary cumulative number, N'_c. The peculiar aspect of these curves is immediately evident; the product curves cross the seed curve, the point of intersection occurring at progressively lower values of N'_c as the amount of growth increases. It is obvious that, unless some crystals grow while at the same time others dissolve, the product curve cannot cross the seed curve. If, however, allowance is made for the variation of shape factor shown in Table 1, the "crossing over" of the size distribution curves does not occur (Fig. 4). Crystals used in the shape factor determinations were obtained from the seeds and products of the runs shown in Figure 4.

Results of Batch Crystallizer Experiments. In order to establish whether or not crystal size influences the rate at which crystals grow in a stirred solution, i.e., whether or not the ΔL law is applicable, a series of eight runs was made under the following conditions:

TABLE 1.—SHAPE FACTOR DETERMINATIONS

Weight of Crystals g.	Number of Crystals, N	L_{av} μ	ρb, g./cc.
0.01611	1292	250	0.778
0.0178	922	290	0.781
0.0303	844	375	0.685
0.0676	834	514	0.599
0.0555	648	535	0.555
0.0914	841	585	0.540
0.2308	999	778	0.489
0.2345	732	877	0.455
0.3249	838	950	0.457

TABLE 2.—RATE OF GROWTH—SUPERSATURATION DATA
(for constant crystal size)

	$L = 300\mu$					
t, min.	21	70	93	109	121	135
v_g, μ/min.	0.15	1.03	1.70	2.25	2.50	2.75
ΔC, g. $CuSO_4 \cdot 5H_2O$ / 100 g. free H_2O	0.32	1.06	1.39	1.61	1.77	1.90
	$L = 400\mu$					
t, min.	92	104	117	130	141	152
v_g, μ/min.	2.34	2.80	3.35	3.95	4.20	4.30
ΔC, g. $CuSO_4 \cdot 5H_2O$ / 100 g. free H_2O	1.37	1.54	1.72	1.86	1.93	1.95
	$L = 500\mu$					
t, min.	121	129	140	150		
v_g, μ/min.	4.75	5.00	5.40	5.65		
ΔC, g. $CuSO_4 \cdot 5H_2O$ / 100 g. free H_2O	1.77	1.85	1.93	1.95		

Seed crystals: 0.50 g./1000 g. solution
Size of seed crystals: 65-100 mesh
Saturation temperature: 28° C.
Cooling rate: 0.02° C./min.
Stirrer speed: 400 rev./min.

The cumulative size distribution curves† are shown in Figure 4. It is evident that ΔL is not constant. The curves of Figure 5 show a marked variation of ΔL with crystal size.

From the curves of Figure 4 the crystal size, L, corresponding to any time of contact, t, can be obtained for any given initial crystal size, L_o; and from plots of L vs. t the instantaneous rate of growth, $dL/dt(=r_g)$, may be readily obtained. Values of r_g obtained in this manner are shown in Table 2.

The supersaturation existing in the solution at any time, t, may be obtained directly from a plot of the resistance data † recorded during the runs.

Since the same conditions were used in all runs, the concentration at any time will be the same in all cases.

From the known variation of crystal size and of rate of growth with time the rate at which a crystal of constant size grows may be determined as a function of time and thus as a function of supersaturation. The rate of growth-supersaturation data for crystals of three different sizes are shown in Table 2 and are plotted in Figure 6. As shown in Figure 7, these data can be correlated by the empirical equation.

$$r_g = 0.00177L^{1.1}(\Delta C)^{1.8} \qquad (6)$$

Although Equation (6) is strictly empirical, it represents the data well. It indicates first, that the rate of growth varies with supersaturation although not linearly, and, second, that the rate of growth depends also on size. Under the conditions used in growing the crystals a small but constant change in temperature occurs, which is not considered in Equation (6). Variations in the viscosity of the solutions over the range of conditions used in the experiments are small and their effect has been neglected. Perhaps the most interesting and significant indication of Equation (6) is the apparent dependency of the growth rate on the crystal size. Speculation on the meaning of this effect narrows down to two questions: (1) Is the rate of growth really dependent upon crystal size, or (2) Is the effect of crystal size actually an apparent effect of some other variable which in turn is related to the size of the crystal? In a stirred solution it is likely that identical suspension of crystals is not obtained and further that the manner of suspension may be a function of crystal size. It is reasonable to expect that the relative velocity between a

† These data are on file with A.D.I.

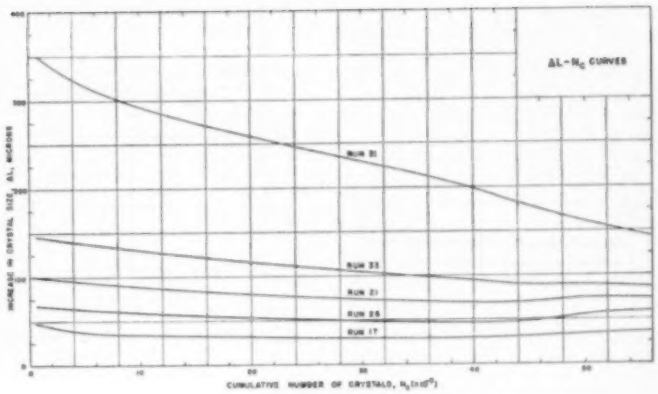

Fig. 5.

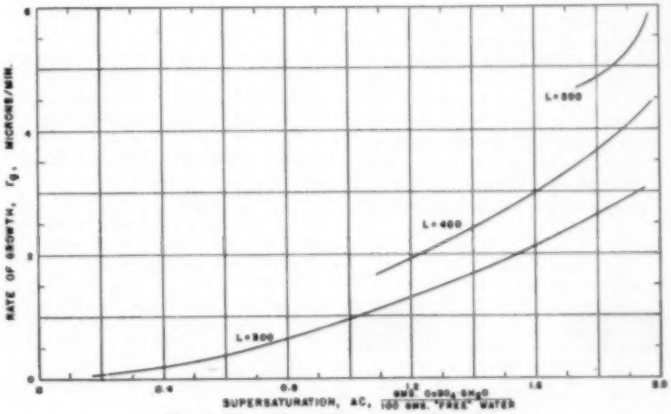

Fig. 6. Rate of growth vs. supersaturation (constant crystal size)

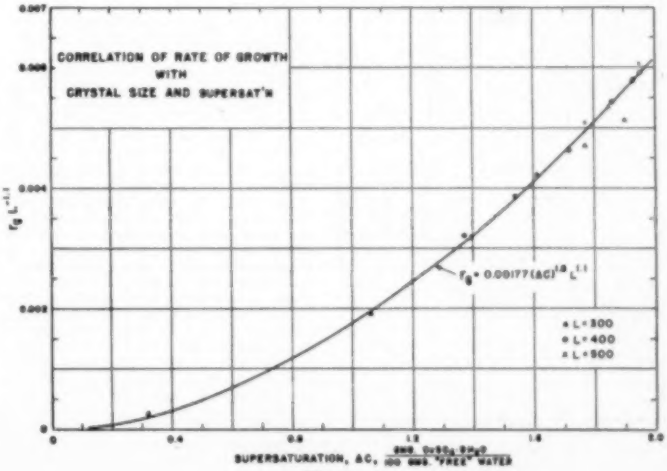

Fig. 7.

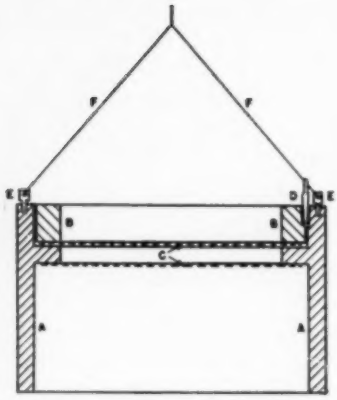

Fig. 8. Sketch of screen assembly.

A. copper tube
B. retainer ring
C. 40-mesh screens
D. retainer pin
E. supporting pins
F. supporting wires

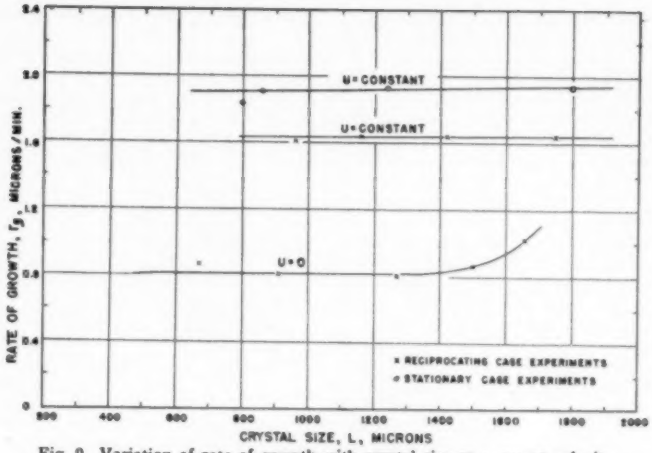

Fig. 9. Variation of rate of growth with crystal size at constant velocity.

crystal and its mother liquor may play an important part in determining the rate of growth.

Because of the empirical nature of Equation (6) and the uncertainties expressed above concerning its validity, a series of experiments was carried out to establish the effect of crystal size and of relative velocity on growth rate.

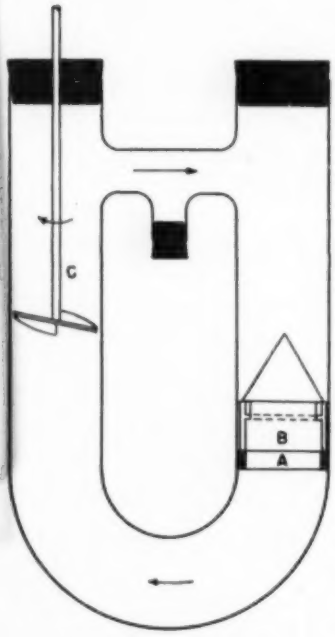

Fig. 10. Sketch of U-tube.

A. rubber ring
B. "cage"
C. 4-bladed stirrer

Effect of Crystal Size on Growth Rate

Rates of growth of crystals of different sizes under controlled solution velocities were determined in two types of apparatus. In the first (reciprocating cage) the crystals were retained between two screens and motion of the crystals with respect to the solution was effected by alternately raising and lowering the screen assembly (Fig. 8) in the solution contained in a 2-in. glass tube. In the second (stationary cage) the solution flowed at a steady rate past crystals retained on a screen in the apparatus shown in Figure 10. The crystals used in determining the effect of crystal size were sufficiently large so that the shape factor was practically constant.

Reciprocating Cage Experiments. In these experiments a small number of especially selected, uniformly sized seed crystals were grown under constant external conditions, i.e., temperature, supersaturation, and relative motion with respect to the solution. Periodically, the crystals were removed from the solution, measured and returned to the solution for further growth. A sufficiently small number of seeds were used so that only a negligible change in concentration occurred over a series of runs. The "cage" with the seeds distributed on the lower screen was carefully lowered into the glass tube containing approximately 400 cc. of solution saturated at 28° C. and maintained at 27° C. and then rotation of the driving arm started. The length of the stroke was 17 cm. The period and amplitude of motion and the temperature of the bath were constant during each single run. Between runs the solution was warmed to dissolve any nuclei present and then recooled to the bath temperature. Fresh solution was used in each series of runs.

Thirteen runs were made in four series of experiments in which the velocity was constant and the average seed size varied from 760μ to 1590μ; 21 runs were made in five series of experiments in which the cage was held motionless and the average seed size varied from 550μ to 1500μ. All these runs were carried out at 27° C.; a solution saturated at 28° C. was used. Table 3 and Figure 9 show the relationship between the rate of growth and size of the crystals (average size of seeds and product).

A small variation in the growth rate with crystal size was found in the runs at zero velocity, but in the other cases, the rate of growth at constant velocity was independent of crystal size.

TABLE 3.—EFFECT OF CRYSTAL SIZE AND SOLUTION VELOCITY ON RATE OF GROWTH

Runs	Velocity* cm./sec.	Av. Crystal Size, μ	Growth Rate, μ/min.
Reciprocating Cage Experiments Effect of Crystal Size			
154-157	0	670	0.88
141-144	0	910	0.82
137-140	0	1270	0.81
149-153	0	1500	0.87
145-148	0	1660	1.03
158-161	3.3	960	1.62
162-164	3.4	1160	1.65
165-167	3.5	1420	1.65
168-170	3.5	1750	1.65
Effect of Solution Velocity		†	
180-183	0.9	730	1.21
177-179	1.8	750	1.36
184-187	2.6	750	1.42
158-161	3.3	760	1.62
171-173	6.9	760	1.47
174-176	13.9	750	1.55
Stationary Cage (U-Tube) Experiments Effect of Crystal Size			
220-222	2.7	800	1.85
200-203	2.7	860	1.92
227-229	2.7	1240	1.95
224-226	2.7	1800	1.94
Effect of Solution Velocity		†	
188-191	0.2	740	1.16
208-211	0.6	720	1.41
192-195	1.0	720	1.53
212-215	1.4	720	1.61
196-199	1.9	730	1.71
216-219	2.3	730	1.80
200-203	2.7	730	1.92
220-222	2.7	720	1.85
204-207	3.6	730	1.92

* For the reciprocating cage experiments these are maximum velocities.
† Average size of seed crystals.

Stationary Cage Experiments. In the apparatus (Fig. 10) used in these experiments liquid, forced upward in one leg of the *U*-tube by a four-bladed stainless steel stirrer, flowed across the bridge and down through the other leg in which the crystals were placed. The cage rested securely on a tight-fitting rubber ring to eliminate any possibility of solution flowing between the cage and the tube wall.

The method of operation used in these experiments was essentially similar to that described in the preceding paragraphs. The *U*-tube was filled with solution, the cage containing the selected seeds was lowered onto the supporting rubber ring and the stirrer was started. At the end of the growth period the crystals were recovered, weighed, and measured. Between runs the cage was carefully washed and dried and sufficient solution added to the tube to make up for that lost on removal of the cage. Fresh solution was used for each series of runs.

Thirteen runs were made in four series of experiments in which the solution velocity was constant and the crystal size varied from 800μ to 1800μ. The relation between the growth rate and the crystal size found in these experiments is shown in Table 3 and Figure 9.

These data and the results of the reciprocating cage experiments show that there is no effect of size on the rate at which crystals grow, provided the liquid velocity does not change.

Effect of Relative Velocity on Rate of Growth. The effect on the rate of crystal growth of the relative velocity between the solution and the crystals has been studied in the same apparatus used to investigate the effects of crystal size. Methods of operation were the same as described above except that the velocity was varied.

Results of 21 runs in six series of experiments in which the average seed size was constant at about 750μ and the crystal-solution velocity varied are summarized in Table 3 and are plotted in Figure 11.

Results of 35 runs carried out at nine different flow rates in the *U*-tube are summarized in Table 3 and plotted in Figure 11.

Comment

In view of the demonstrated absence of any effect of crystal size on the rate of growth, the apparent presence of such an effect in the data on crystals grown in a stirred solution must be attributed to differences in relative velocities on the crystals of different sizes. The conclusion is drawn that the rate of growth is a function of supersaturation and of crystal-solution velocity but is independent of size per se.

Even though apparently good agitation is used in many industrial crystallizers, the relative velocities, particularly of small crystals, are normally quite low; and considerable difference exists between the relative velocities of large and of small crystals. Results of this investigation show that under such conditions the rate of growth of the larger crystals is favored over that of the smaller ones.

Effect of Size on Rate of Growth. In the development of the ΔL law it was assumed that the crystals were suspended under identical conditions and that the shape factor was constant. Results of the investigation of the effect of crystal size on the rate of growth provide additional evidence that the ΔL law is valid if the assumed conditions obtain. Results indicate further, that, assuming constancy of shape factor, this law holds for the case in which the relative velocity of the crystals are sufficiently high so that velocity no longer affects the growth rate. However, in most industrial crystallizers it is doubtful if these conditions are met and therefore the ΔL law cannot be safely applied.

Rate of Growth Data. Inspection of Figure 11 shows that as the relative velocity between the solution and the crystals increases, the growth rate increases rapidly from a finite value and approaches asymptotically a rate independent of velocity. The existence of the asymptote strongly suggests that there is a finite rate of crystallization at the interface which is independent of the crystal-solution velocity and which soon becomes controlling as this velocity is increased. The effect of velocity in the low range suggests the usual effect of velocity on mass transfer to the interface through the liquid phase.

At the low velocities used in these experiments (equivalent to modified Reynolds numbers of 0 to 30) it might be expected that the coefficient of mass transfer to the interface would be proportional to a concentration difference; the over-all rate would then be given by the equation

$$\frac{1}{r_g} = \frac{1}{a\sqrt{u}} + \frac{1}{r_i} \qquad (7)$$

It is obvious that Equation (7) does not check the data of Figure 11 because it is inconsistent with the finite growth rate at zero velocity. Also Equation (6) shows that the over-all growth rate is not proportional to the over-all concentration difference, and therefore, the rates of the two series reactions assumed in writing Equation (7) are not both proportional to the concentration difference.

The failure of Equation (7) led to the test of an empirical equation of the following form to correlate the rate data:

$$\frac{1}{r_g} = \frac{1}{f(u)} + \frac{1}{r_i} \qquad (8)$$

where $f(u)$ is a function of velocity. By assuming a reasonable value for $1/r_i$ and plotting the data of Table 3 (stationary cage experiments) as $1/r_g$

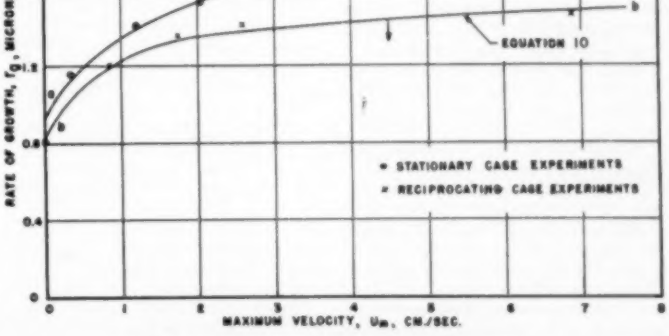

Fig. 11. Effect of velocity on rate of growth.

vs. u, it was found that the function $f(u)$ is empirically linear in u.

The over-all rate can be written, therefore, as

$$\frac{1}{r_g} = \frac{1}{r_o + \beta u} + \frac{1}{r_i} \tag{9}$$

For the U-tube experiments the empirical values of r_o, β, and r_i are 1.65, 3.5 and 2.20 respectively. A plot of Equation (9) with these constants is shown as line a-a in Figure 11.

Correlation of the rate data obtained in the reciprocating cage experiments by Equation (9) requires an equation that takes into account the velocity variation due to the cyclic motion of the cage. The total growth of each crystal during one quarter of a revolution of the driving mechanism is

$$\Delta L = \int_0^{\pi/2\omega} r_g dt$$

Substituting the expression for r_g from Equation (9) and expressing in terms of the angular velocity, ω, and the radius of the crank, R, yields an expression for the average growth rate,

$$r_g(av.) = \frac{2\omega\Delta L}{\pi}$$

$$= r_i\left(1 - \frac{2r_i}{\pi}\int_0^{\pi/2} \frac{dx}{a + k\ cos\ x}\right) \tag{10}$$

in which $a = r_o + r_i$, $k = 1.91\omega\beta R$, and $x = \omega t$.

The constant 1.91 is the ratio of the gross area to the net area of the reciprocating cage.

For the reciprocating cage experiments, the maximum velocity, u_m, is ωR and $k = 1.91\beta u_m$. Data for the reciprocating experiments show an asymptote of $r_i = 1.6$ rather than the value of 2.2, found in the stationary cage experiments. Values of r_o and β found in the stationary cage experiments, however, fit the results from the reciprocating cage experiments and therefore, $k = 6.68\ u_m$. Values of $r_g(av.)$ vs. u_m calculated from Equation (10) are plotted as curve $b - b$ in Figure 11.

Interpretation of Equation (9). Equation (9), due to its empirical nature, is probably an oversimplified version of the proper basic equation which is still unknown. It may be interpreted, however, as follows: the mass transfer to the interface, the rate of which is given by the term $(r_o + \beta u)$, consists of two parallel processes, a diffusion effect independent of velocity and a flow effect dependent on velocity. The mass transfer is followed in series by a reaction at the interface. The variation of the rate of this reaction in the two sets of growth experiments as shown by the two different values of r_i, is not surprising as it is known that the rate of such a reaction is sensitive to small amounts of impurities in the crystallizing solution. It is possible that the purity of the solution was not constant in both cases as no special effort was made to purify rigorously the solutions used.

In the usual types of industrial crystallizers the larger crystals, because of their higher settling velocities, will tend to move through the solution faster than the smaller crystals. In both cases the velocities of movement through the solution will be low and in a range where the velocity is an effective variable. Such conditions favor the preferential growth of the larger crystals, which usually is desirable. The size distribution of the product from such crystallizers shows this effect qualitatively.

Summary

Results of this investigation may be summarized as follows:

a. The size of a crystal is not a direct or primary factor in determining the rate at which it grows.

b. The rate of growth of a crystal increases as the velocity with which it moves relative to the surrounding solution increases. This increase of growth rate is quite appreciable in the low velocity range but becomes progressively less as the velocity is increased and soon becomes practically negligible. These results are consistent with the theory that the growth process consists of a mass transfer of solute to the solution—crystal interface followed by an interfacial reaction.

c. An apparent effect of size on growth rate is obtained if the relative velocities of crystals of different sizes differ and if the velocities are in the low range where they are effective.

These results indicate that in industrial crystallizers the growth rate will be a function of crystal size and the growth of larger crystals will be favored.

Notation

b = shape factor, volumetric
C = concentration, g. salt/100 g. "free" water
L = average size of crystals, μ
n, N = number of crystals
N' = arbitrary number of crystals
r = rate of growth, μ/min.
R = radius of crank arm, cm.
s = distance travelled by cage from center point
t = time, min.
u = velocity, cm./sec.
w, W = mass of crystals, g.
α, β = constant
Δ = finite change
θ = angle between crank arm and horizontal, radians
ρ = density, g./cc.
ω = angular velocity of crank, radians/min.

SUBSCRIPTS:

c refers to cumulative number of crystals
g refers to over-all growth
i refers to interface
L refers to crystals of specific average size
m refers to crystals measured; also to maximum conditions
o refers to initial conditions; also to zero velocity

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ISOTHERMAL FREE JETS OF AIR MIXING WITH AIR

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Free jets of air mixing isothermally with the surrounding air are described. Jets from nozzles with diameters of 0.50, 0.75 and 0.90 in. were used at initial velocities from 30 to 800 ft./sec. These jets had a flat velocity profile at the nozzle exit. Radial profiles of momentum flux velocity were measured at a number of positions along the jet axis with a 0.065 in. O.D. impact tube. The resulting momentum flux velocity profiles were correlated in terms of six dimensionless ratios on a generalized basis and on this basis were found to be essentially independent of the initial jet velocity and jet diameter in the ranges covered. Near the nozzle the relations were expressed graphically. At distances greater than 10- to 15-nozzle diameters the ratio of the momentum flux velocity to the momentum flux velocity along the axis was related to a relative radius by an error-type function independent of the distance from the nozzle.

The momentum flux velocity profiles were corrected to mean velocity profiles and were then used to determine the mass flowing across the plane of the profile per unit time. At distances greater than 15-nozzle diameters the mass flow increases linearly with distance.

A JET of fluid entrains and mixes with another fluid in a number of important engineering applications. These include the simple mixing of fluid streams, entrainment in jet pumps and ejectors, spray drying, combustion of gas, oil, and powdered coal, gas-phase chemical reactions and similar operations. This paper describes experiments with a jet of air issuing into the air of the room and at the same temperature as the room.

It is characteristic of such a jet that considerable turbulence is generated and the turbulence level throughout most of the jet is higher than that normally encountered in flow through straight pipes and ducts. The component, u, in one direction of the instantaneous velocity at a point in turbulent flow may be represented by

$$u = \bar{u} + u' \qquad (1)$$

where $\bar{u}$ is the time average of the velocity component and u' is the instantaneous fluctuation from this mean. The time average of u' is thus zero by definition. However, the time average of the square of the fluctuating component $\overline{u'^2}$ is not zero. An ideal impact tube will measure $\rho\overline{u^2}$. This can be expressed in terms of average and fluctuating velocity components at constant density by

$$\rho\overline{u^2} = \rho\bar{u}^2 + \rho\overline{u'^2} \qquad (2)$$

Thus, the evaluation of the mean velocity component $\bar{u}$ requires a knowledge of the term $\overline{u'^2}$ in addition to impact tube measurements. The mean velocity $\bar{u}$ is required to determine the mass velocity at any point. This is $\rho\bar{u}$ or at constant density $\rho\bar{u}$.

An impact tube was used throughout this work. Since this does not measure the mean velocity the measurements are reported as momentum flux velocities defined as

$$\sqrt{\frac{\rho\overline{u^2}}{\rho}}$$

which becomes $\sqrt{\overline{u^2}}$ at constant density. This is not in general equal to $\bar{u}$. The average velocity component $\bar{u}$ was estimated in a few cases by taking into account the value of $\sqrt{\overline{u'^2}}$ as determined by Corrsin (5).

Experimental Apparatus

The experimental apparatus consisted essentially of an air source, a flow control and metering system, a flow nozzle, and an impact tube mounted on a mechanism for traversing in three directions. The flow diagram is shown in Figure 1.

The air was supplied by a diesel-driven air compressor with a capacity of 500 std. cu.ft./min. at a pressure of 100 lb./sq.in. gage. The compressor was of the two-stage type with interstage cooling. It was connected to an aftercooler through a section of flexible pipe inserted to eliminate vibrations. The air then passed through an oil and moisture separator into two air receivers with a total capacity of about 200 cu.ft. Two ceramic filters downstream of the air receivers were used to remove entrained oil and water.

Pressure regulation was accomplished by means of two control valves, one for flows up to 50 std.cu.ft./min. and the other for flows up to 350 std.cu.ft./min., both valves having a pressure control range of from 0 to 100 lb./sq.in. gage. The metering system consisted of a set of nine critical orifice plates that covered a range of flows from 0.5 to 350 std.cu.ft./min. The critical orifice plates were inserted between two flanges fitted with three asymmetrically located pins that allowed only one orientation of each orifice plate. A standard 0.952-in. diameter flow nozzle was used to calibrate the orifice plates with an accuracy of $\pm\frac{1}{2}\%$ (δ). The pressure upstream of the orifice plate was measured with a bourdon-type gage with a precision of $\frac{1}{4}\%$ of the full scale reading. A bulb-type dial thermometer measured the upstream temperature within $\pm 2°$ F. The pressure downstream from the orifice plate was checked with a bourdon-type gage to insure that the downstream to upstream pressure ratio was less than the critical pressure ratio at all operating conditions.

Temperature control of the air was by means of four shell and tube heat exchangers in series, each with a surface area of about 35 sq.ft. The heat exchangers could be supplied either with water at about 215° F. from a steam boiler or with cold

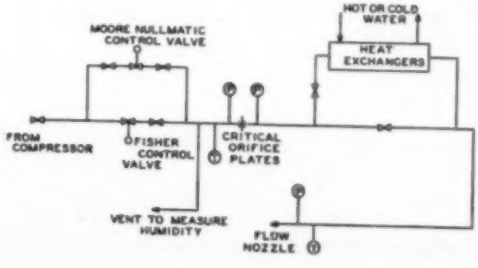

Fig. 1. Flow diagram of experimental apparatus.

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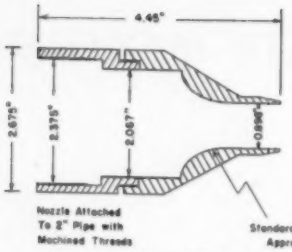

Fig. 2. 0.9-in. ASME nozzle.

water from the main. Temperature control was effected by by-passing part of the metered air and mixing it with the stream from the heat exchangers. The temperature just upstream from the flow nozzle was controlled and adjusted to compensate for the temperature drop in the adiabatic expansion of the air through the nozzle so that the temperature of the air discharging from the nozzle was the same as that of the air in the room.

The nozzle upstream pressure and the impact tube pressures were measured with a series of three manometers, a 40-in. mercury manometer, a 40-in. water manometer, and a micromanometer of the Wahlen gage-type (*14*) which could detect pressures of from 0.001 to 1.000 in. of alcohol.

Several different flow nozzles were used in the experiments all having an ASME long radius-low ratio-type (*2*) approach section but having different throat diameters, throat lengths and exterior designs. The principal features of these nozzles are listed below. The 0.500- and one of the 0.900-in. nozzles had throats as specified by the ASME. The other 0.900-in. nozzle had a throat section 1.5 in. longer than specified by the ASME. The 0.750-in. nozzle was equipped with interchangeable extensions as shown in Figure 3. Only the 1.25-in. extension of this nozzle was used in these tests. (*See* Table A, p. 179.)

The impact tube traversing mechanism allowed movement in the direction of flow of the jet from the plane of the nozzle discharge to 100-cm. distance, lateral movement for ±30 cm. from the jet center line, and vertical movement from the jet center line of ±25 cm. The traversing apparatus consisted of two horizontal steel rails parallel to the jet axis and one horizontal rail normal to the jet axis. *V*-notches were milled the length of the two rails and a single ball-bearing moved in each notch serving as the end support for the cross rail. The surface of the cross rail was ground on the top and one side. A carriage rode on these ground surfaces. The impact tube was mounted on a ⅞-in. diameter rod in a vertically adjustable support on the cross carriage. This mechanism was aligned with the nozzle axis within 2 mm. in 60 cm. The location of the impact tube was determined by meter scales on the three coordinate axes.

The impact tube was constructed from No. 16 hypodermic needle tubing (0.065-in. O.D.) and was calibrated against the standard flow nozzle by placing its tip at a distance of ½ a nozzle diameter from the plane of discharge of the nozzle. The velocity at this point is the same as the velocity at the nozzle exit and at this distance from the nozzle the impact tube did not change the effective cross section of the nozzle throat. The velocity profile at the nozzle discharge was uniform within as close to the wall of the throat as the impact tube could be placed. The nozzle discharge velocity could thus be computed from the mass rate of flow and the air density. The density of the air was corrected for water content by a humidity measurement taken upstream of the critical orifice plate (*8*). Air was bled off into a chamber containing a wet- and a dry-bulb thermometer. Calibration of the impact tube was made over a range of velocities from 2 to 1100 ft./sec.

Experimental Results

The turbulent velocity fluctuations in a free jet are sufficient to effect measurements with an impact tube. From a momentum balance around an impact tube it may be shown that the quantity measured is the mean value of the product of density and the square of the instantaneous velocities $\overline{\rho u^2}$. This is related to the mean velocity by Equation (*2*).

The term $\overline{\rho u^2}$ represents the momentum flux in a region of constant density. This may be compared with the types

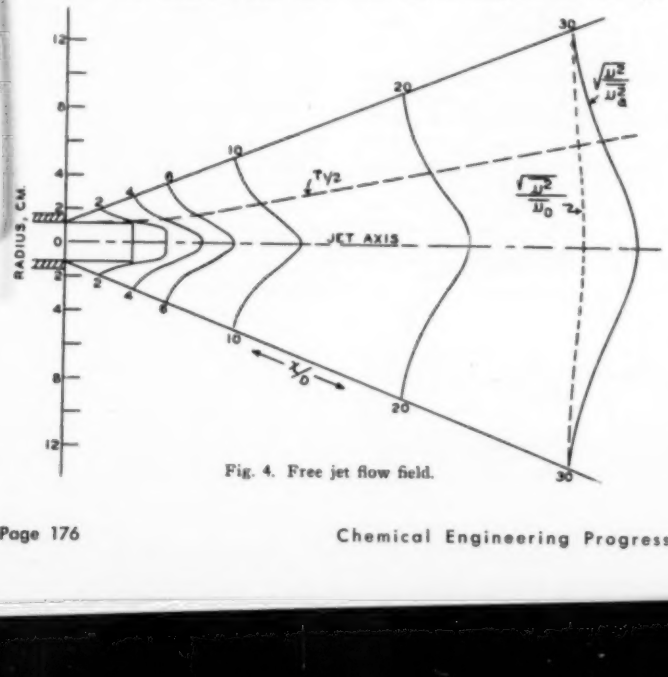

Fig. 4. Free jet flow field.

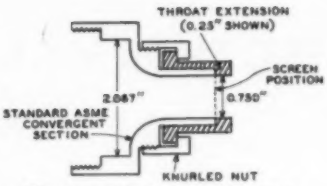

Fig. 3. 0.75-in long throat nozzle.

of flow normally encountered in straight pipes and ducts. The term including the fluctuating components of the velocity is then usually negligible and the impact tube measures the square of the mean velocity.

In a free jet the fluctuating component of velocity is not negligible and the effect is included in measurements with the impact tube. The velocities reported here are thus the square root of the momentum flux divided by the air density and may be considered as the mean velocity $\bar{u}$ only when the turbulent components of the velocity can be neglected. The values computed from the impact tube measurements will be designated as momentum flux velocities.

Distribution of the momentum flux velocity ratio in a free jet is shown in Figure 4. Distribution of this ratio at the exit of the nozzle is uniform and as the jet spreads in the region near the nozzle exit, a portion of the profile remains uniform for a certain distance from the nozzle. This is the region of the "potential cone" in which the velocity is equal to the discharge velocity. Distances from the nozzle are expressed as nozzle diameters, and velocity ratio profiles are shown at distances of 2-, 4-, 6-, 10-, 20-, and 30-nozzle diameters. The profiles are the ratio of the momentum flux velocity at any point r to the momentum flux velocity at r equal 0 (the jet axis). All the profiles, therefore, have a maximum value of unity on the jet axis. The dotted profile shown at the right of the figure is the momentum flux velocity relative to the nozzle discharge velocity as a function of r and indicates the relative velocities at this distance as compared with the initial velocity of the air issuing from the nozzle.

A radius indicative of the jet spread is termed $r_{1/2}$ and is defined as the radius at which the momentum flux velocity on a given profile is one half the momentum flux velocity on the jet axis at that distance. Such a defined radius is necessary since there is no ready means of determining the jet boundary. The boundaries shown in Figure 4 are fictitious and are included only to clarify the representation of the jet. Location of the $r_{1/2}$ radius is shown.

The radial distribution of momentum flux velocity is considered in three re-

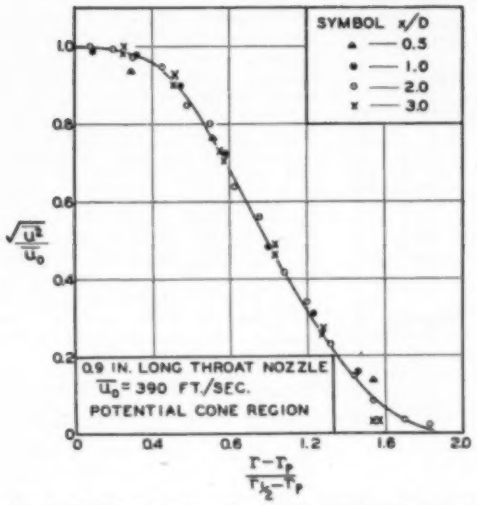

Fig. 5. Radial distribution of momentum flux velocity ratio.

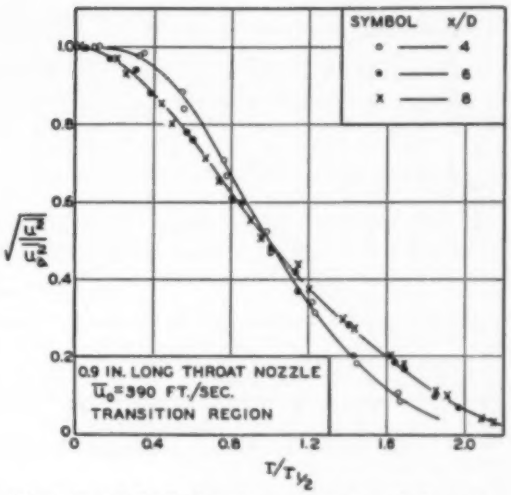

Fig. 6. Radial distribution of momentum flux velocity ratio.

gions of the jet: region of the potential cone, a transition region, and region of fully developed flow.

In the potential cone region the momentum flux velocity profiles for the 0.900-in. long throat nozzle have been correlated by a single empirical curve for profiles taken at distances of 0.5-, 1.0-, 2.0-, and 3.0-nozzle diameters. The empirical correlation was obtained for the data in this region by considering the portion of the profiles outside the potential cone. The potential cone length was 3.5-nozzle diameters, and the radius of the potential cone at any distance from the nozzle could be determined from the equation:

$$\frac{r_p}{D} = \frac{3.5 - x/D}{7.0}$$

Using this radius, the momentum flux velocity ratio

$$\sqrt{\frac{\overline{u^2}}{\bar{u}_0}}$$

was plotted as a function of

$$\frac{r - r_p}{r_{1/2} - r_p}$$

The coordinates of the resulting generalized curve are given in Table 1.

The momentum flux velocity ratio at a discharge velocity of 390 ft./sec. at distances of 0.5-, 1.0-, 2.0-, and 3.0-nozzle diameters with the 0.900-in. long throat nozzle is shown in Figure 5. The

TABLE 1.—GENERALIZED POTENTIAL CONE REGION

$(r - r_p)/(r_{1/2} - r_p)$	$\sqrt{\overline{u^2}/u_0}$
0.0	1.000
0.2	0.993
0.4	0.957
0.6	0.856
0.8	0.693
1.0	0.500
1.2	0.325
1.4	0.178
1.6	0.069
1.8	0.018

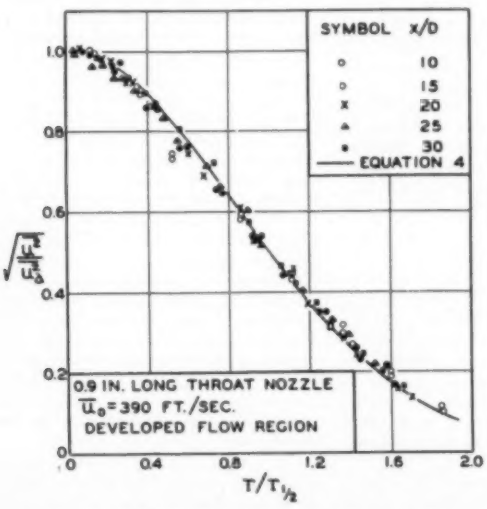

Fig. 7. Radial distribution of momentum flux velocity ratio.

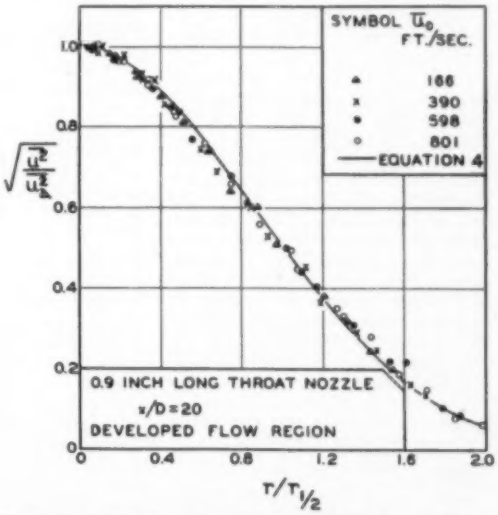

Fig. 8. Radial distribution of momentum flux velocity ratio.

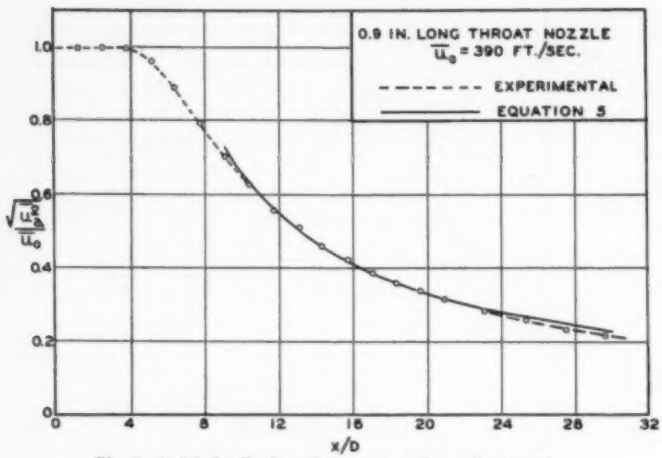

Fig. 9. Axial distribution of momentum flux velocity ratio.

correlation is independent of distance and nozzle discharge velocity within the accuracy of the data. Baron and Alexander (*3*) have computed values for profiles at distances of one and two diameters. Their calculated points were converted to the same basis as used in the empirical correlation by means of the potential cone equation (Eq. (3)) and were found to be in agreement with this correlation.

In the transition region of the jet, the velocity profiles change in shape from that of the potential cone region to the general profile that is found in the region of fully developed flow. This transition is shown in Figure 6 for the 0.900-in. long throat nozzle at distances of 4, 6, and 8-nozzle diameters. At distances of 10-nozzle diameters and greater, the velocity profiles are of the same shape, and the flow has become fully developed.

Figure 7 shows a plot of the momentum flux velocity ratio distributions in the developed flow region for a discharge velocity of 390 ft./sec. at distances of 10-, 15-, 20-, 25-, and 30-nozzle diameters, vs. the ratio $r/r_{1/2}$ for the 0.900-in. long throat nozzle. The data at several distances from the nozzle are well represented by the empirical curve drawn through them. The same curve is shown in Figure 8 at a distance of 20-nozzle diameters for the 0.900-in. long throat nozzle with nozzle discharge velocities of 166, 390, 598, and 801 ft./sec. The data again are well represented over this range of nozzle velocities. The curves shown in both Figures 7 and 8 are expressed by the relation:

$$\sqrt{\frac{\overline{u^2}}{\overline{u_a}^2}} = e^{-\ln 2(r/r_{1/2})^2} \qquad (4)$$

A typical axial distribution of momentum flux velocity is shown in Figure 9, in which the dotted curve is drawn through the experimental points and the solid curve is of the form of the equation:

$$\sqrt{\frac{\overline{u^2}_a}{\overline{u}_o}} = \frac{1}{2c_1 x/D} \qquad (5)$$

with $c_1 = 0.0754$. The potential cone region is in evidence in the figure where the velocity is constant with distance. Equations (4-6) are similar to those used by Reichardt (*10*) for a point source jet. Their agreement with the experimental data indicates that the finite source jet begins to behave as a point source jet at a distance of about 10 diameters from the nozzle.

Values of $r_{1/2}$ for a discharge velocity of 390 ft./sec. are shown in Figure 10 for profiles taken at several distances from the nozzle. The solid curve represents the equation for the $r_{1/2}$ distribution obtained from the equation used by Reichardt (*10*).

$$r_{1/2} = c_2 x \sqrt{\ln 4} \qquad (6)$$

with $c_2 = 0.0725$. The conservation of momentum flux from one cross section of the jet to another requires that the values of c_1 and c_2 as determined from the axial distribution of velocity and from the $r_{1/2}$ distribution respectively must be equal. The values of c_1 and c_2 determined above are not quite equal. This discrepancy will be discussed hereinafter.

Radial and axial profiles of velocity were taken with the 0.500-in. ASME nozzle, the 0.750-in. long throat nozzle, and the 0.900-in. ASME nozzle in addition to the 0.900-in. long throat nozzle already described. The constants characteristic of the flow produced by the several nozzles are given in Table 2. There is a slight tendency for the values of both c_1 and $r_{1/2}/D$ to increase with decreasing nozzle diameter. At distances of 2- and 6-nozzle diameters, the values of $r_{1/2}/D$ for the two 0.900-in. nozzles and the 0.750-in. nozzle were in complete agreement and did not indicate any trend with the change in nozzle diameter.

The form of the radial distributions of momentum flux velocity ratio was independent of the changes in nozzle diameter as is shown in Figure 11.

TABLE 2.—CONSTANTS FOR FLOW FROM SEVERAL NOZZLES

Nozzle Throat	Throat Diameter (in.)	$x/D = 20$ c_1	$r_{1/2}/D$
ASME	0.9	0.0754	1.692
Long	0.9	0.0754	1.715
Long	0.75	0.0741	1.727
ASME	0.5	0.0794	1.795

Discussion of Results

The discrepancy in the values of the constants, c_1 and c_2, as calculated from the axial distribution of the momentum flux and as determined from the slope of the $r_{1/2}$ distribution appears to indicate that the total momentum flux at any cross section is a function of the distance from the nozzle. The total momentum flux ratio may be determined by combining Equations (4-6) and integrating across the section resulting in the relation

$$\frac{m}{m_o} = \left(\frac{c_2}{c_1}\right)^2 \qquad (7)$$

where m and m_o are the total momentum flux at any plane x and at $x = 0$ respectively. The constants c_1 and c_2 are from Equations (5) and (6) respectively. For the momentum flux to be conserved the two values of c must be equal. The discrepancy between c_1 and c_2 obtained in the experiments can be traced most logically to the techniques of measurement used. The pressure throughout the jet was assumed constant. It can be shown that even when the pressure varies somewhat this would not lead to inequality of the constants c_1 and c_2 as determined here. The impact tube was calibrated in a uniform flow at a low turbulence level. Under these conditions the effect of angle of attack can also be observed. However, such a calibration does not correct for any effect due to the marked fluctuations in both velocity and in angle of attack encountered in the free jet. Measurements with the impact tube near the exit to a nozzle fitted with a screen to generate turbulence indicated that turbulence level should be taken into account in the calibration of the impact tube. The different values of c_1 and c_2 are probably indicative of the limitations imposed on the accuracy of the measurements by the turbulence.

The entrainment by the jet may be obtained by determining the distribution of the mass velocity $\rho\bar{u}$ at any cross section and carrying out a suitable inte-

gration over the section. The calculation of the average velocity $\bar{u}$ from the momentum flux velocities requires a correction for $\overline{u'^2}$. This term may be measured with a hot wire anemometer and such measurements have been made by Corrsin in free jets issuing at somewhat lower velocities than those used here. These values may be used to convert the present measurements to average velocity provided the turbulence level distribution does not change appreciably with velocity. This was assumed to be the case and the average velocity computed from the relation:

$$\bar{u} = \frac{\sqrt{\overline{u^2}}}{(1+Z^2)^{1/2}} \qquad (8)$$

The distribution of the momentum flux velocity along the axis for the 0.750-in. nozzle with a 1.25-in. throat extension is shown in Figure 12. The calculated axial distribution of the average component of velocity is shown for comparison. The difference is not great. The radial distribution of these two quantities at a single value of x/D is shown in Figure 13. The ratio of $\bar{u}/\bar{u}_a$ is plotted against $r'_{1/2}$ which is based on $\bar{u}$. This differs slightly from $r_{1/2}$ and serves to bring the two curves together.

The entrainment ratio in a free jet is defined as

$$\frac{M}{M_o} = \frac{2\pi\rho \int_o^\infty \bar{u} r dr}{A\rho\bar{u}_o} \qquad (9)$$

where M is the mass flux crossing any plane at a distance x/D from the nozzle, M_o is the mass flux from the nozzle at $x/D = 0$, and A is the cross-sectional area of the nozzle throat. From the distribution of mean velocity computed above, the mass flux at x/D was 5.14 times the mass flux from the nozzle. The general equation for the distribution of the mass flux with distance in the developed flow region of the jet may be obtained from the equations for the axial and radial distributions of $\bar{u}$, and from the $r'_{1/2}$ distribution:

$$\frac{\bar{u}}{\bar{u}_a} = e^{-\ln 2\left(\frac{r}{r'_{1/2}}\right)^2} \qquad (10)$$

$$\frac{\bar{u}_a}{\bar{u}_o} = \frac{1}{2c_1' x/D} \qquad (11)$$

$$\frac{r'_{1/2}}{D} = c_2' \sqrt{\ln 4}\, \frac{x}{D} \qquad (12)$$

When these equations are substituted into Equation (9), the relation obtained for the mass flux is:

$$\frac{M}{M_o} = \frac{4c_2'^2}{c_1'} \cdot \frac{x}{D} = 0.246\,\frac{x}{D} \qquad (13)$$

If the momentum flux velocity is used (i.e., Eqs. (4-6)) instead of $\bar{u}$ the equation for the mass flux is:

$$\frac{M}{M_o} = \frac{4c_2^2}{c_1} \cdot \frac{x}{D} = 0.264\,\frac{x}{D} \qquad (14)$$

which differs from Equation (13) by 7.3%. This is indicative of the error in a mass balance which arises from neglecting the turbulent fluctuations.

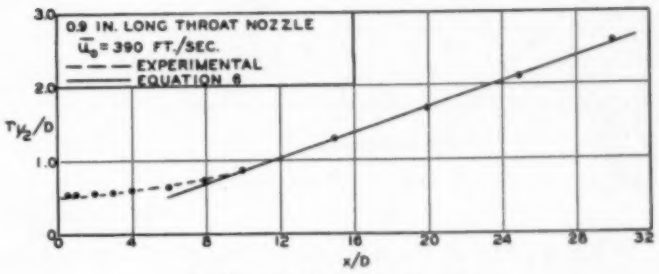

Fig. 10. Axial distribution of $r_{1/2}/D$.

Comparison with Other Investigators. Velocity distributions in axially symmetrical free jets have been measured by several investigators (*1, 4, 5, 9, 11, 13*). In most cases impact tubes were used. Corrsin used a hot wire anemometer as well. Table 3 shows a comparison of the constants c_1 and c_2 calculated from the data obtained with impact tubes by others in this work.

Albertson et al reported their data in the form of an equation based on the conservation of momentum. This arbitrarily makes c_1 equal to c_2. In all the other cases c_2 is always less than c_1. The hot wire anemometer measurements of Corrsin yielded average values of the resultant velocity instead of the axial component of the momentum flux velocity as measured here and cannot be compared directly. Albertson and also

TABLE A.

Nozzle Diameter in.	Extension of Throat Length	
0.500	ASME	
0.750	1.25[1]	Long Throat
0.900	ASME	Fig. 2
0.900	1.5[1]	Long Throat

[1] Length in inches as extension to ASME throat specifications.

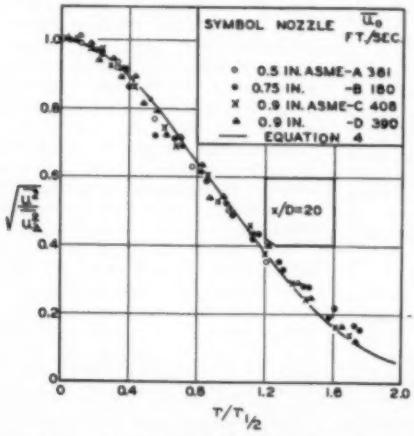

Fig. 11. Radial distribution of momentum flux velocity ratio.

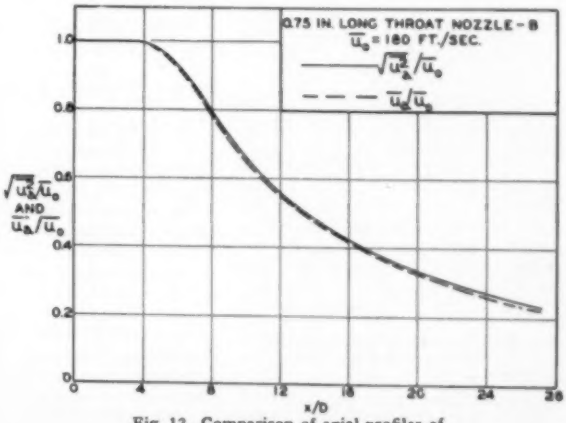

Fig. 12. Comparison of axial profiles of $\sqrt{\overline{u^2}_a}/\bar{u}_o$ and $\bar{u}_a/\bar{u}_o$

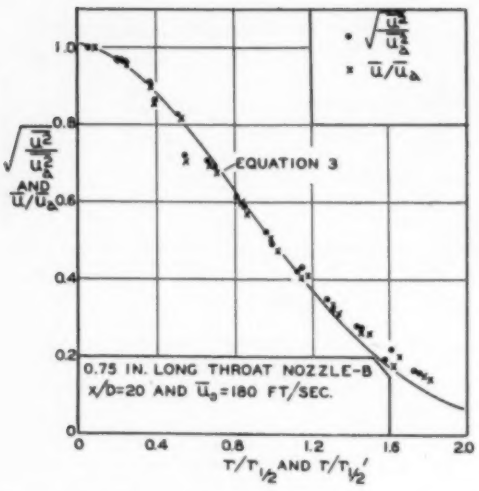

Fig. 13. Comparison of radial profiles of $\sqrt{\overline{u^2}/\overline{u^2}_a}$ **and** $\bar{u}/\bar{u}_a$

Keagy and Weller used equations similar to (4-6). The values of c_1' and c_2' for the component of the mean velocity determined by the method already described, are 0.0763 and 0.0685 respectively.

None of the investigators corrected his impact tube readings for the velocity fluctuations and therefore all impact tube data reported are distributions of the square root of the momentum flux and not the mean velocity. The correction to impact tube data to obtain mean velocities has been described by Goldstein (*7*) and by Corrsin (*5, 6*).

Conclusions

The flow field of a free jet issuing from a round finite source may be generalized and the momentum flux velocity distributions correlated by utilizing the dimensionless groups

$$\sqrt{\frac{\overline{u^2}}{\overline{u_a^2}}},\ \frac{\sqrt{\overline{u_a^2}}}{\overline{u_o}},\ \frac{x}{D},\ \frac{r_{1/2}}{D},\ \frac{r}{r_{1/2}}$$

and

$$\frac{r - r_p}{r_{1/2} - r_p}.$$

The nozzle discharge velocity and the nozzle design affect the generalized correlations only slightly.

It is necessary to correct impact tube readings for the presence of velocity fluctuations in order to compute the mean velocity and the mass flux, which requires that a knowledge of the turbulence level be available for all points where impact tube readings are taken.

In the highly turbulent flow field of a free jet the momentum flux velocity differs as much as 12% from the mean velocity.

TABLE 3.—COMPARISON OF RESULTS OF SEVERAL INVESTIGATORS

Investigator	c_1	c_2
Albertson, et al	0.0806	
Corrsin and Uberoi	0.0751	0.0691
Keagy and Weller (0.750-in. long throat nozzle u_o = 178 ft./sec.)	0.0862	0.0754
	0.0747	0.0702

Notation

A = cross-sectional area of the nozzle throat
c_1 = axial distribution constant for momentum flux velocity
c_2 = radial distribution constant for momentum flux velocity
c_1' = axial distribution constant for mean velocity
c_2' = radial distribution constant for mean velocity
D = nozzle diameter
m = momentum flux
m_o = momentum flux at $x/D = 0$
M = mass flux
M_o = mass flux at $x/D = 0$
$r_{1/2}$ = radius at which $\sqrt{\overline{u^2}/\overline{u_a^2}} = 0.5$
$r_{1/2}'$ = radius at which $\bar{u}/\bar{u}_a = 0.5$
r_p = radius of potential cone
u = x-component of instantaneous velocity at (x, r)
$\bar{u}$ = x-component of mean velocity at (x,r)
u' = x-component of fluctuating velocity (x, r)
u_a = x-component of instantaneous velocity at (x, o)
u_o = x-component of instantaneous velocity at (o, o)
x, r = cylindrical coordinates
Z = turbulence level
ρ = air density

Acknowledgment

This paper contains a part of the results obtained in an investigation in the Engineering Experiment Station of the University of Illinois on a contract with the Office of Naval Research, Number N6-ori-71 Task Order XI, entitled "Mixing of Fluid Streams."

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The data which provide the basis for this paper are tabulated in reference 12.

Discussion

S. J. Friedman (Du Pont Co., Wilmington, Del.): As you have pointed out, I believe Hunter Rouse presented the same equations that you are presenting about a year ago (*Trans. Am. Soc. Civil Engrs.*). How closely do the constants you obtained for these equations agree with the constants which Rouse proposed?

E. W. Comings: In general the results are comparable. I am not sure that we should expect them to be identical. Hunter Rouse used a vertical jet from a flat surface. In this work the jet was from a nozzle with a streamline exterior surface (*see* Table 3).

Anonymous: In your work have you been able to approximate the effect of a wall arranged in a cylindrical manner? What effect would it have on the distribution?

E. W. Comings: That effect was not measured in the experiments described here. Work is being done, however, that should give this information. The apparatus consists of a jet issuing parallel to a wall and also a jet issuing into a cylinder. These simple shapes should provide a good basis from which to proceed.

(Presented at Forty-second Annual Meeting, Pittsburgh, Pa.)

MOMENTUM, MASS, AND HEAT TRANSFER IN FREE JETS

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Transfer of flux of momentum, mass, or heat in jets from point or finite sources is basic to chemical engineering problems such as the design of combustion chambers, spray dryers, and air atomizers. Equations based on a generalization of Reichardt's hypothesis are derived for the distributions of the fluxes in such jets. These equations are solutions of a differential equation which is linear in the various fluxes. Hence, the distributions from a number of point sources can be superimposed in cases where the boundary conditions can be satisfied. This method has been used to predict the momentum flux distribution adjacent to a finite nozzle with good agreement with experimental measurements. An explanation is given for discrepancies between data obtained by various authors on temperature and concentration distributions in free jets, and the turbulence measurements necessary for comparison with the equations for heat and mass flux are indicated.

THE transfer of momentum, mass, and heat from turbulent fluid streams to adjacent solid boundaries is familiar to all engineers. In many cases, the existence of a laminar sublayer, adjacent to the solid boundaries, has been considered responsible for the major resistance to transfer. The large number of semiempirical and theoretical equations available for these cases involve the concept of molecular transfer through the laminar sublayer with suitable corrections to account for the resistances introduced by a transition layer and the turbulent core.

In another class of transport problems there are no solid boundaries, and the entire resistance to transport of momentum, mass, and heat is in the turbulent fluid. For instance, in a gas burner a combustible gas issues from a nozzle and entrains and mixes with air. The position of the flame and the design of the combustion chamber are determined by the turbulent transfer accompanied by chemical reaction. Similar considerations apply to the design of combustion chambers using atomized or powdered fuel. In general, transfer phenomena in free jets underlie the basic problems of other operations such as atomization and spray drying.

The theoretical as well as the practical importance of free-jet processes is attested by the numerous contributions in the literature such as Tollmien (*38*), Howarth (*17*), Tomotika (*39*), and Abramovich (*1*), all based on the phenomenological theories of turbulent transfer of either Prandtl (*26*) or Taylor (*34*). The result of these analyses concerning the distribution of mean velocity, temperature, and concentration in free jets appears in the form of infinite series, and gives a reasonable qualitative picture of free jets. They fall short of quantitative agreement with recent data. In connection with these mixing length theories, it is of interest to note that Hinze (*16*), by basing his solution on the use of an eddy viscosity independent of radial position, obtained results in as good agreement with the data as those of Tollmien or Tomotika.

These theoretical approaches involve assumptions concerning the dependence of either mixing length or eddy viscosity on radial position. Since there appears to be little phenomenological basis for such assumptions, an altogether different approach is desirable. In this connection, Reichardt's work is of importance (*28*). Noticing that the radial distribution of axially directed momentum flux can be correlated by an error-curve, he investigated the assumptions required to obtain an error-curve as a solution of the equations of motion. While the phenomenological basis of his work is uncertain (*27*), it is felt that a re-examination and extension of his treatment are desirable.

In the present work, Reichardt's hypothesis is generalized. Differential equations are derived which, in addition to yielding the desired error-curves, are also linear in the fluxes of momentum, heat, and jet fluid. The linearity of these equations implies that the solutions of more complicated problems may be obtained by superimposing particular solutions.

Analytical Considerations. A differential equation for the fluxes of the momentum, mass, and heat may be obtained by equating the rate of accumulation of any of these entities in a volume, τ, to the sum of their rates of generation inside the volume and their rates of transport through the surface, σ. Letting ϕ denote the concentration of any of these entities

$$\frac{\partial}{\partial t}\iiint_{\tau} \psi d\tau = \iiint_{\tau} Q d\tau + \iint_{\sigma} \boldsymbol{D}\nabla\psi d\sigma - \iint_{\sigma} \psi V d\sigma \tag{1}$$

here the first term denotes the rate of accumulation, the second the rate of generation, the third the rate of transport by molecular processes, and the fourth the flux associated with fluid motion.

Table 1 shows the variables to be substituted in Equation (1) for ψ, Q, and $\boldsymbol{D}$ for the specific cases of momentum, mass, or heat transfer.

By means of the divergence theorem, Equation (1) may be transformed.

$$\nabla \boldsymbol{D}\nabla\psi - \nabla\psi V + Q = \frac{\partial\psi}{\partial t} \tag{2}$$

Substituting into Equation (2) the variables given in Table 1, one obtains a differential equation for the transfer of heat, another for the transfer of matter, and the three equations of motion.

Focusing attention on a free jet, and assuming that the generation and molecular transfer terms are negligible, one obtains for the quasi-steady state (steady state with respect to the time-mean components)

$$\overline{\nabla \cdot \psi V} = 0 \tag{3}$$

where the bar indicates the operation of time-averaging. In cylindrical coordinates, as suggested by the axial symmetry of the jet,

$$\frac{\partial \overline{\psi u}}{\partial x} + \frac{1}{r}\frac{\partial r\overline{\psi v}}{\partial r} = 0 \tag{4}$$

When the flux originates wholly in the nozzle

$$\int_{o}^{\infty} \psi u 2\pi r dr = (\psi u)_o A_o \tag{5}$$

which simply states the conservation of the flux and is an obvious result of the assumption that the generation terms are negligible.

Before proceeding with the general case, consider the transport of the axial component of momentum for a jet of uniform density. For this case, Equation (4) becomes

$$\frac{\partial \overline{u^2}}{\partial x} + \frac{1}{r}\frac{\partial r\overline{uv}}{\partial r} = 0 \tag{6}$$

Reichardt (*28*), knowing that an equation of the type

$$\overline{u^2} = \frac{K}{b^2} e^{-\left(\frac{r}{b}\right)^2} \tag{7}$$

correlates experimental results in a satisfactory manner, pointed out that Equation (7) is a solution of Equation (6), provided

$$\overline{uv} = -\Lambda \frac{\partial \overline{u^2}}{\partial r} \tag{8}$$

where Λ is a function of the axial distance alone. For the present case of rotational symmetry

$$\Lambda = \frac{b}{2}\frac{db}{dx} \tag{9}$$

Substituting Equations (8) and (9) into Equation (6)

$$\frac{\partial \overline{u^2}}{\partial x} - \frac{b}{2r}\frac{db}{dx}\frac{\partial}{\partial r}\left[r\frac{\partial \overline{u^2}}{\partial r}\right] \tag{10}$$

Equation (10), in addition to yielding a solution in agreement with experiment, is also linear in the momentum flux.

Returning to the general case, consider the following generalization of Equation (7).

$$\overline{\psi u} = \frac{1}{f_1(x)} e^{-\left[\frac{r}{f_2(x)}\right]^2} \tag{11}$$

In order to satisfy Equation (5)

$$f_1(x) = \frac{\pi f_2^2(x)}{(\psi\mu)_o A_o} \tag{12}$$

and to satisfy the additional assumption that the flux profiles at successive sections through the jet are similar

$$f_2(x) = Cx \tag{13}$$

Equation (11) then becomes

$$\overline{\psi u} = \frac{(\overline{\psi u})_o A_o}{\pi C^2 x^2} e^{-\left(\frac{r}{Cx}\right)^2} \tag{14}$$

By analogy with Equations (8) and (9), since $b = f_2(x) = Cx$

$$\overline{\psi v} = \frac{C^2 x}{2}\frac{\partial \overline{\psi u}}{\partial r} \tag{15}$$

Substituting Equation (15) into Equation (4) one obtains

$$\frac{\partial \overline{\psi u}}{\partial x} - \frac{C^2 x}{2r}\frac{\partial}{\partial r}\left[r\frac{\partial \overline{\psi u}}{\partial r}\right] = 0 \tag{16}$$

a differential equation which is linear in $\overline{\psi u}$. For a point source of flux Equation (14) is a solution of Equation (16). In view of the linearity of the latter, it is possible to obtain solutions for combinations of point sources by superimposing solutions of the type of Equation (14), provided the assumptions leading to Equation (16) are valid and provided the boundary conditions can be satisfied. Consider, for instance, the case of a number of parallel free jets issuing from point sources. The distribution of the flux should be given by

$$\overline{\psi u} = \sum_i \frac{(\overline{\psi u})_{o,i} A_i}{\pi C^2 x_i^2} e^{-\left(\frac{r_i}{Cx_i}\right)^2} \tag{17}$$

Table 1 may now be used in conjunction with Equations (16) and (17) to obtain the various distribution functions for free jets. For single point sources, the distribution of axially directed momentum flux is

$$\overline{\rho u^2} = \frac{(\overline{\rho u^2})_o A_o}{\pi C_m^2 x^2} e^{-\left(\frac{r}{C_m x}\right)^2} \tag{18}$$

for heat flux, where c_p is independent of θ and χ

$$\overline{\rho\theta u} = \frac{(\overline{\rho\theta u})_o A_o}{\pi C_\theta^2 x^2} e^{-\left(\frac{r}{C_\theta x}\right)^2} \tag{19}$$

and for the flux of jet fluid

$$\overline{\rho\chi u} = \frac{(\overline{\rho\chi u})_o A_o}{\pi C_\chi^2 x^2} e^{-\left(\frac{r}{C_\chi x}\right)^2} \tag{20}$$

Comparison with Experimental Data. To compare Equations (18)-(20) with experiment, data are needed from which the total fluxes can be obtained as a function of position in the jet. The type of data required may be seen when these equations are expanded in terms

TABLE 1.—INTERPRETATION OF ψ, Q, $\mathbf{D}$ FOR SPECIFIC CASES

Case	ψ	$\mathbf{D}$	Q
Momentum transfer	ρu_j	ν	$X_j - \frac{\partial P}{\partial x_j}$
Mass transfer	$\rho\chi$	D	$Q\chi$
Heat transfer	$c_p\rho\theta$	α	$Q\theta$

of the mean and fluctuating components.

$$\frac{\overline{(\bar{\rho}+\rho')(\bar{u}+u')(\bar{u}+u)}}{(\rho u^2)_o} = \frac{A_o}{\pi C_m^2 x^2} e^{-\left(\frac{r}{C_m x}\right)^2} \tag{21}$$

$$\frac{\overline{(\bar{\rho}+\rho')(\bar{\theta}+\theta')(\bar{u}+u')}}{(\rho u\theta)_o} = \frac{A_o}{\pi C_\theta^2 x^2} e^{-\left(\frac{r}{C_\theta x}\right)^2} \tag{22}$$

$$\frac{\overline{(\bar{\rho}+\rho')(\bar{\chi}+\chi')(\bar{u}+u')}}{(\rho\chi u)_o} = \frac{A_o}{\pi C_\chi^2 x^2} e^{-\left(\frac{r}{C_\chi x}\right)^2} \tag{23}$$

Expanding the left-hand members, neglecting third-order terms, and recognizing that all terms containing only one fluctuating component must vanish

$$R_m\left(\frac{\overline{\rho u^2}}{\rho_o u_o^2}\right) = \frac{A_o}{\pi C_m^2 x^2} e^{-\left(\frac{r}{C_m x}\right)^2} \tag{24}$$

$$R_\theta\left(\frac{\overline{\rho\theta u}}{\rho_o\theta_o u_o}\right) = \frac{A_o}{\pi C_\theta^2 x^2} e^{-\left(\frac{r}{C_\theta x}\right)^2} \tag{25}$$

$$R_\chi\left(\frac{\overline{\rho\chi u}}{\rho_o\chi_o u_o}\right) = \frac{A_o}{\pi C_\chi^2 x^2} e^{-\left(\frac{r}{C_\chi x}\right)^2} \tag{26}$$

Where

$$R_m = 1 + 2\frac{\overline{\rho' u'}}{\bar{\rho}\bar{u}} + \frac{\overline{u'^2}}{\bar{u}^2} \tag{27}$$

$$R_\theta = 1 + \frac{\overline{\theta' u'}}{\bar{\theta}\bar{u}} + \frac{\overline{\rho' u'}}{\bar{\rho}\bar{u}} + \frac{\overline{\theta'\rho'}}{\bar{\theta}\bar{\rho}} \tag{28}$$

$$R_\chi = 1 + \frac{\overline{\chi' u'}}{\bar{\chi}\bar{u}} + \frac{\overline{\rho' u'}}{\bar{\rho}\bar{u}} + \frac{\overline{\chi'\rho}}{\bar{\chi}\bar{\rho}} \tag{29}$$

Following Corrsin (*8*), ρ' may be approximated by,

$$\rho' = -\frac{\bar{\rho}}{\bar{\theta}+T_a}\theta' - \frac{\bar{\rho}}{\bar{\chi}+S}\chi' \tag{30}$$

where

$$S = \frac{\frac{M_o}{M_a}}{1-\frac{M_o}{M_a}} \tag{31}$$

These equations may be used to eliminate ρ' from Equations (*27*)-(*29*).

Corrsin (*9*) describes methods of measuring

$$\frac{\overline{u'^2}}{\bar{u}^2}, \frac{\overline{\theta'^2}}{\bar{\theta}^2}, \frac{\overline{\chi'^2}}{\bar{\chi}^2}, \frac{\overline{\theta' u'}}{\bar{\theta}\bar{u}}, \text{ and } \frac{\overline{\chi' u'}}{\bar{\chi}\bar{u}}$$

by means of a hot-wire anemometer. The mean temperature, $\bar{\theta}$, can be measured with a thermocouple, the mean concentration by standard methods of gas analysis. The mean density, $\bar{\rho}$, can then be computed from the mean concentration and temperature by the use of a suitable equation of state. The mean velocity, $\bar{u}$, may be evaluated from

$$\bar{u} = \left[\frac{\overline{\rho u^2}}{\bar{\rho} R_m}\right]^{1/2} \tag{32}$$

where the term ρu^2 is measured with a total-head impact tube.

The necessary hot-wire anemometer measurements have not been made in sufficient quantity to provide a test of Equations (19) and (20). Corrsin (*8*) reports data for the intensity of the velocity and temperature fluctuations in a nonisothermal jet; however, his values of $\overline{\theta' u'}$ scatter widely. To our knowledge, measurements of $\overline{\chi' u'}$ and $\overline{\chi'^2}$ have not been reported. Hinze (*6*) and Keagy (*18*) report data from which the distribution of mean temperature, $\bar{\theta}$, concentration, $\bar{\chi}$, and velocity, $\bar{u}$, may be computed. Integration of the products $\bar{\rho}\bar{\theta}\bar{u}$ and $\bar{\rho}\bar{\chi}\bar{u}$ over the radius of the jet gives the fraction of the total flux transported by the mean components. Results obtained from Hinze's and Keagy's data are shown in Table 2.

Equations (*26*) and (*29*) indicate that similarity among concentration profiles obtained by using jet fluids of widely varying molecular weights should not be expected. This is immediately evident upon recognizing that some of the terms in Equation (*29*) may be either positive or negative, depending upon the ratio of the molecular weight of the jet fluid to that of the ambient fluid. (*See* Eqs. (*30*) and (*31*)). Similar considerations apply to nonisothermal jets. In view of this, the variation of the fractions of total flux transported by the mean components is not unexpected, and it is clear that the mean component fluxes alone cannot be correlated on the basis of a conservative relation.

The total-head impact tube provides, in theory, a means of measuring directly the momentum flux density. Numerous investigations of the distribution of momentum flux in free jets, in which impact tubes were used, have been reported in the literature. Of the investigators, three groups have used error-curves for the correlation of their data. Reichardt (*29*), using Equation (9), found $db/dx(=C_m)$ to be 0.072. Albertson, *et al.* (*2*), by correlating the distribution of the root mean square axial velocity, $\sqrt{\overline{u'^2}}$ (by means of an equation which may be obtained by extracting the square root of both sides of Equation (18) and assuming the density to be uniform) found C_m to be 0.081. Taylor, *et al.* (*37*), found second-order variations in C_m with initial velocity, and report an average value of 0.075 for the range of initial velocities from 300 to 400 ft./sec.

As has been noted, Equation (18) applies only to point sources. However, the natural consequence of Reichardt's hypothesis is the linearization of the equation of continuity of flux (Eq. (16)); and, therefore, the sum of particular solutions of the error-curve type provides a solution for free-turbulence problems for which the boundary conditions can be satisfied and for which the assumptions made in deriving Equation (16) hold.

Grimmett (*15*) has obtained data on the flow field formed by the confluence of two parallel jets which support the principle of superposition. These will be published in due course.

The authors have measured momentum flux distributions adjacent to a flow nozzle. A difficulty in applying Equation (18) to this case arises from the well-known fact that there is a non-turbulent conical region in the flow field throughout which the velocity is essentially uniform. This region has its base on the rim of the nozzle and its apex on the axis of flow at approximately four-nozzle diameters from the nozzle. Clearly, Reichardt's hypothesis holds for the trivial case where there is no velocity gradient perpendicular to the mean-flow, as is the case inside this non-turbulent cone. The principle of superposition may thus be applied to the cone as well as the turbulent zone, but it may break down in the region of transition between the two zones. The assumption may therefore be made that the plane of a finite nozzle discharge comprises

TABLE 2.—FRACTION OF TOTAL FLUX TRANSPORTED IN A FREE JET BY THE MEAN COMPONENTS

Jet	Fraction Transported	Observer
Air, **D** = 30° C.	0.7 (Heat flux)	Hinze
1.1% Town gas in air	0.8 (Mass flux)	Hinze
Carbon dioxide	0.6 (Mass flux)	Keagy
Nitrogen	0.9 (Mass flux)	Keagy

an infinite number of elemental point sources.

The summation in Equation (17) may be replaced by integration

Where (s,γ) is a system of polar coordinates in the plane of the nozzle discharge. After a value of C_m has been assigned, Equation (33) can be evaluated most conveniently by numerical methods.

$$(\overline{\rho u^2})_{x,r} = \int_0^{\frac{d}{2}} \int_0^{2\pi} \frac{(\overline{\rho u^2})_{o,s}}{\pi C_m^2 x^2} e^{-\left(\frac{r^2 + s^2 - 2rs\cos\gamma}{C_m^2 x^2}\right)} s\,ds\,d\gamma \qquad (33)$$

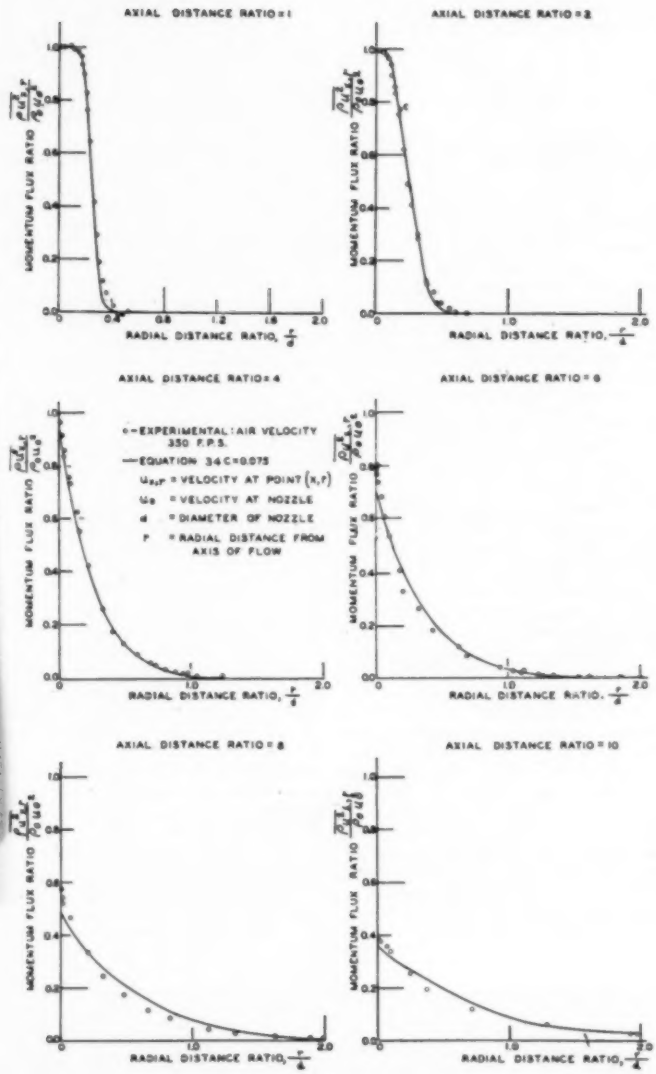
RADIAL PROFILES OF MOMENTUM FLUX IN A FREE, TURBULENT JET OF AIR ADJACENT TO THE NOZZLE
AXIAL DISTANCE RATIO = 1
AXIAL DISTANCE RATIO = 2
AXIAL DISTANCE RATIO = 4
AXIAL DISTANCE RATIO = 6
AXIAL DISTANCE RATIO = 8
AXIAL DISTANCE RATIO = 10
MOMENTUM FLUX RATIO
RADIAL DISTANCE RATIO, r/d
o = EXPERIMENTAL: AIR VELOCITY 350 F.P.S.
— EQUATION 34 C = 0.075
$u_{x,r}$ = VELOCITY AT POINT (x,r)
u_o = VELOCITY AT NOZZLE
d = DIAMETER OF NOZZLE
r = RADIAL DISTANCE FROM AXIS OF FLOW

Fig. 1.

Total-head impact tube measurements were taken in the flow field of a free jet in the region adjacent to a nozzle having an I.D. of 2.28 cm. The apparatus and techniques used have been described by Taylor, *et al.* (*37*). Air was discharged from the nozzle at a velocity of 350 ft./sec.

The results are shown in Figure 1, where the momentum flux ratio is plotted as a function of the radial distance ratio for various axial distance ratios. The solid lines represent Equations (34) with C_m equal to 0.075.

The calculated curves, which result from the recognition of the linearization of the equation of continuity by application of Reichardt's hypothesis, show good agreement with the experimental data. The discrepancies observed may possibly arise from the existence of the transition zone at the boundary of the nonturbulent cone. Thus it appears that the assumptions made in linearizing the equations of transfer are useful for this case of free turbulent flow, and the investigation of their application to problems of heat and mass transfer are warranted.

Conclusions

1. Reichardt considered a point source free turbulent jet and proposed that the radial flux density of momentum is proportional to the radial gradient of the axial flux density of momentum. This relationship may be generalized to apply to the flux of mass and heat under similar conditions.

2. When this relationship is incorporated into the differential equations for the transport of momentum, mass, and heat, these equations become linear in the flux densities, thus simplifying their use in certain applications involving the turbulent transport of these quantities.

3. Reichardt's equation leads to a solution for point source free jets giving the radial distribution of axial momentum flux in the form of an error-curve in good agreement with experimental data.

4. The differential equations, due to their linear properties, show that the distributions from a number of point sources may be superimposed or added in cases where the boundary conditions can be satisfied. This method has been used to predict the axial momentum flux distribution adjacent to a finite nozzle with good agreement with experimental measurements. The method holds much promise for obtaining solutions involving the simultaneous transport of momentum, mass and heat in the turbulence associated with free jets and possibly elsewhere.

Notation

A = cross-sectional area of nozzle discharge

C = spreading coefficient

C_m = spreading coefficient for momentum transfer

C_θ = spreading coefficient for heat transfer

C_χ = spreading coefficient for mass transfer

c_p = local specific heat

D = molecular diffusivity

$\boldsymbol{D}$ = coefficient of molecular transport

K = constant, function of nozzle diameter and initial velocity

M_o = molecular weight of jet fluid

M_a = molecular weight of ambient fluid

P = static pressure

Q = rate of generation of transport quantity per unit volume

Q_χ = rate of chemical generation of a molecular species per unit volume

Q_θ = rate of generation of heat per unit volume

$R_m R_\theta$, R_χ = functions defined by Eqs. (27), (28), and (29)

S = ratio defined by Eq. (32)

T = local, instantaneous, abs. temperature

T_a = abs. temperature of ambient fluid

V = local, instantaneous, vector velocity

X = body forces

b = function proportional to jet width, $b = Cx$

d = diameter of nozzle discharge

r = radial distance from axis of flow

s = radial polar coordinate

t = time

u = local, instantaneous, axial component of velocity

v = local, instantaneous, radial component of velocity

x = distance from nozzle along axis of flow

GREEK:

α = molecular thermal diffusivity

γ = angular polar coordinate

∇ = vector operator, del

θ = local, instantaneous temperature difference, $\theta = T - T_a$

Λ = function of x

ν = molecular kinematic viscosity

ρ = local, instantaneous density

σ = surface enclosing arbitrary volume of fluid

τ = volume

χ = local, instantaneous concentration of jet fluid

ϕ = local, instantaneous concentration of any entity

SUBSCRIPTS:

$_a$ = ambient conditions

$_i$ = ith point source

$_j$ = component or coordinate in j-direction

$_o$ = nozzle conditions

SUPERSCRIPTS:

$-$ and $'$ denote time-mean and fluctuating components of any variable, e.g., $u = \overline{u} + u'$

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EXTRACTION OF COBALTOUS CHLORIDE WITH CAPRYL ALCOHOL IN A SPRAY TOWER*

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BECAUSE of the similar properties of nickel and cobalt, their separation has presented considerable difficulty to the metallurgy industry. At present, the most widely used processes involve the precipitation of the cobalt in the form of the hydrated cobaltic oxide ($Co_2O_3 \cdot 3H_2O$) by the addition of an alkaline solution of an oxidizing agent to an acid solution of the divalent salts. Suitable oxidizing agents include bleaching powder, sodium and potassium hypochlorite and hypobromite, and solid carbonates in conjunction with chlorine gas (*2, 8, 10, 12, 14*).

Garwin and Hixson (*6*) have carried out a systematic investigation of the possibility of the separation of the chlorides of nickel and cobalt by selective extraction with an organic solvent. Capryl alcohol (2-octanol) was found to be a satisfactory selective solvent for $CoCl_2$ when certain electrolytes, such as HCl or $CaCl_2$, were present to a considerable extent in the water phase. Separation factors (ratio of $CoCl_2$ to $NiCl_2$ in the solvent relative to that in the water phase at equilibrium) of 40 to 90 were obtained when HCl was the added electrolyte, and 10 to 17 in the presence of $CaCl_2$. Values of the distribution coefficients (D) for $CoCl_2$ in $CoCl_2$-HCl-water solutions, and for $CoCl_2$ and $NiCl_2$ in $CoCl_2$-$NiCl_2$-HCl-water solutions at 25° C., reported by these investigators, are shown as a function of the total chloride concentration in the water phase in Figure 1. Curves 2 and 3 of Figure 1 are extrapolated somewhat as indicated by the dotted portions, in order that the results for some of the runs to be reported in this paper, made at total chloride concentrations in the water phase slightly higher than the range investigated by Garwin and Hixson, might be calculated.

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* Supplementary data of Tables 1 and 2 are on file (Document 3184) with the American Documentation Institute, 1719 N Street, Northwest, Washington, D. C. Obtainable by remitting $1.00 for microfilm and $3.30 for photoprints.

Only one study of the rate of extraction of an inorganic salt from aqueous solution by an organic solvent has thus far been reported. Geankoplis and Hixson (*7*) carried out the extraction of $FeCl_3$ from an aqueous HCl solution in a spray tower, using isopropyl ether as the solvent and with the organic phase dispersed. The effect of $FeCl_3$ concentration and varying solvent rate on the $(H.T.U.)_{ow}$ were investigated. At high ether rates the $(H.T.U.)_{ow}$ was found to be constant at about 0.7 ft., independent of the $FeCl_3$ concentration. It was found also that, contrary to previously reported data, there was a considerable end-effect at the continuous phase entrance to the tower.

The present work was undertaken in order that the extraction capacity coefficients K_1a and K_Wa and the over-all heights of a transfer unit $(H.T.U.)_{0.1}$ and $(H.T.U.)_{ow}$ might be obtained for the two systems: $CoCl_2$-HCl-water-capryl alcohol (Series I) and $CoCl_2$-$NiCl_2$-HCl-water-capryl alcohol (Series II) when the extraction of the $CoCl_2$ is carried out countercurrently in a spray tower, when the transfer takes place from the water to the alcohol phase and when the alcohol phase is dispersed. Hydrochloric acid was chosen as the added electrolyte instead of $CaCl_2$ because of the higher separation factors, the greater equilibrium degree of extraction of the $CoCl_2$ by the solvent, and the greater ease of recovering the solutes for re-use.

The $CoCl_2$ concentration in the water phase was held between 7.7 and 11.2 wt. % in the runs of Series I. In Series II, the total salt concentration was approximately 9 wt. % with a cobalt-to-nickel ratio about 1.3 to 1.

Materials Used

Capryl alcohol—Hardesty Chemical Co. chemical grade—contained less than 2.0 wt. % methyl hexyl ketone as the major impurity.
HCl—met A.C.S. specifications for purity
$CoCl_2 \cdot 6H_2O$—Baker's analyzed grade
$NiCl_2 \cdot 6H_2O$—Baker's analyzed grade
Water—laboratory distilled
Analytical reagents—met A.C.S. specifications for purity

Apparatus. A 1¼-in. I.D. tower 68½ in. long, with end designs and disperser of the type suggested by Blanding and Elgin (*1*) and Johnson and Bliss (*9*), respectively, was constructed of Plexiglas. (*See* Fig. 2.)

Preliminary work with the system capryl alcohol-water showed that the type of disperser used was necessary to overcome tendencies for the alcohol to spread over a flat distributor plate, especially at the lower alcohol rates. Ten dispersing tips, each 0.1 in. I.D. and ¼ in. long, arranged in a triangle with ¼ in. between centers, produced drops of the dispersed phase of the most uniform size over the range of flow rates desired. These drops, essentially spherical in shape, were estimated at 1/8 to 3/16 in. in diameter for the system used in the extraction studies.

A diagram of the extraction equipment is given in Figure 3. Storage vessels for the aqueous feed, solvent, extract and raffinate were 5-gal. Pyrex bottles. Pressure for moving the aqueous feed and solvent was applied to the storage vessels by means of compressed nitrogen from a standard cylinder. Reduction of the pressure from cylinder pressure to 3 to 5 lb./sq.in. was accomplished by means of an ordinary pressure regulator. The regulator was protected from hydrochloric acid vapor by the use of a section of standard 1-in. iron pipe filled with Ascarite and placed between the regulator and the lines to the feed and solvent bottles.

All transfer lines were either 3/8 or 7/16-in. O.D. Saran tubing, with fittings of Saran, glass and rubber.

Flow rates of the aqueous feed and solvent were indicated by the pressure drop across a capillary tube in the line. Inclined tube manometers filled with mercury were the pressure drop indicating devices. Control of the rates was accomplished by adjusting a screw clamp operating on a short length of rubber tubing.

The interface level inside the upper settling chamber was adjusted by the proper vertical positioning of a vented tee in the raffinate line.

Procedure. Since it was desired that essentially no hydrochloric acid be transferred as the two phases flowed countercurrent through the tower, the original solutions were prepared so that the aqueous and alcohol solutions contained HCl concentrations very nearly in equilibrium. The alcohol was brought to the proper HCl concentration by shaking with concentrated aqueous HCl and allowing the phases to separate. The acid phase was transferred to another container and was used to make up the aqueous feed. To this acid was added the cobalt salt, or the mixture of cobalt and nickel salts, and sufficient HCl to produce the concentrations desired. The

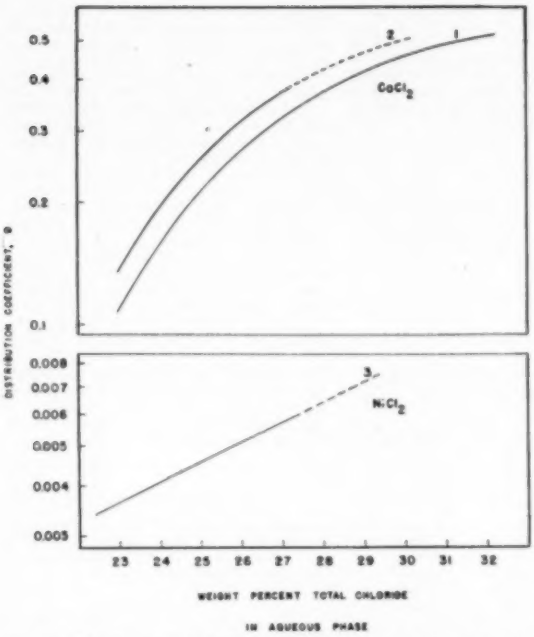


Fig. 1. Distribution of $CoCl_2$ and $NiCl_2$ between capryl alcohol and water in presence of HCl. Garwin and Hixson (*6*).

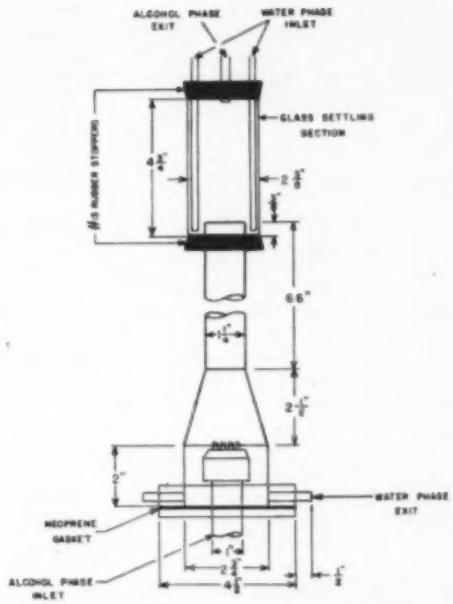


Fig. 2. Details of extraction column construction.

Concentration limits (wt. % in water phase)

	$CoCl_2$	$NiCl_2$
Curve 1	9.5-12.7	0.0
Curves 2 and 3	5.6-6.6	5.4-6.5

total chloride concentration of the aqueous feed was about 30 wt. % and the total salt concentration about 8 to 11 wt. %.

In making a run, aqueous feed and solvent were charged to the feed vessels, pressure was applied above the liquids and the transfer lines were filled by opening the control valves momentarily. The alcohol rate was maintained at a low value, just great enough to prevent the denser water phase from displacing the alcohol in the disperser assembly while the tower was being filled with the continuous water phase. When the tower was full, the flow rates of both phases were adjusted to the desired values; measurements were made by observing the time for a given volume of exit fluid to be collected. The inclined tube manometers were used only as indicating devices for aiding in maintaining constant rates of flow.

Steady-state operation was assumed to be reached after about three complete changes of the continuous phase in the tower. Samples of the extract and raffinate were collected and stoppered and the flows of the aqueous feed and solvent then stopped. The aqueous feed and solvent were also sampled for analysis.

There was no tendency for emulsion formation and no difficulties were experienced in this regard.

It was necessary to recover both the cobalt chloride and capryl alcohol because of the limited supply of each available. This was done by repeated washing of the extract with about a 25% aqueous hydrochloric

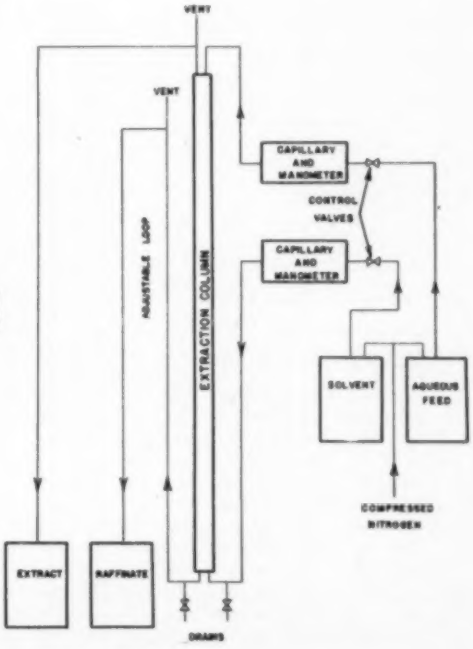


Fig. 3. Diagram of extraction column and auxiliaries.

acid solution. Although removal of the cobalt chloride was not complete with this operation, the salt concentration was lowered to 0.5% or less, depending on the thoroughness of washing. Subsequent separation of this aqueous extract was effected by simple distillation of the HCl and water to the point of $CoCl_2$ dryness. Hydrochloric acid vapor coming off first in this distillation was absorbed in an HCl-water mixture from a previous distillation to bring its HCl concentration up to 25%. The solid cobalt salt recovered from the distillation was dissolved in the raffinate from the run just completed so that the resulting solution was suitable for use as the next aqueous feed without further treatment.

The temperature of operation was room temperature, 73 to 89° F. Equilibrium data at 25° C. (77° F.) were used in the calculation of the extraction capacity coefficients since it was found by Garwin and Hixson (6) that increasing the temperature from 25° to 50° C. produced a comparatively small change in the equilibrium distribution of cobalt chloride and nickel chloride.

In the analysis of samples, total chloride was determined by the Volhard method, total salts by an evaporation procedure, nickel by dimethylglyoxime precipitation, and cobalt by difference.

Specific gravity was determined with a Westphal balance. The data are part of Tables 1 and 2. Surface and interfacial tension measurements were obtained on a few selected samples with a du Nuoy tensiometer. The data are given in Table 3.

Calculations. At any point in an extraction column operating under steady-state conditions, the rate at which material is being transferred may be represented by the following equations:

$$dN = K_A(C_A^* - C_A)dA \qquad (1)$$

$$dN = K_W(C_W - C_W^*)dA \qquad (2)$$

adV may be inserted for dA, and if the driving force for mass transfer is assumed to be linear with mass transfer, Equation (1) may be integrated to give:

$$N = K_A a(\Delta C_A)_{lm} V \qquad (3)$$

or

$$K_A a = \frac{N}{V(\Delta C_A)_{lm}} \qquad (4)$$

N is defined as

$$N = S(L_{A1}C_{A1} - L_{A2}C_{A2}) \qquad (5)$$

If it is assumed that the volume change of the phase under consideration is negligible as solute is transferred, Equation (5) reduces to:

$$N = SL_A(C_{A1} - C_{A2}) \qquad (6)$$

The over-all *H.T.U.* (3) based on the alcohol phase is, then:

$$(H.T.U.)_{OA} = \frac{H}{\left[\frac{C_{A1} - C_{A2}}{(\Delta C_A)_{lm}}\right]} = \frac{L_A}{K_A a} \qquad (7)$$

Similar equations may be derived for the water phase in which the subscript W is substituted for subscript A in Equations (3)-(7).

TABLE 1

RUN	FLOW RATE		SPECIFIC GRAVITY				#CoCl2/cu.ft.				% TOTAL DEVIATION(a) IN MATERIAL BALANCE
	cu.ft./hr.-sq.ft.		Alcohol		Water		Alcohol		Water		
	Alcohol phase	Water phase	In	Out	In	Out	In	Out	In	Out	
1	45.2	49.1	0.921	0.921	1.202	1.190	0.00	1.36	6.05	4.70	+ 6
1R	95.7	49.1	0.935	0.906	1.196	1.176	0.19	1.15	6.31	4.56	+ 2
5	89.8	49.4	0.901	0.909	1.197	1.177	0.22	1.19	6.30	4.35	+12
11	108	48.1	0.903	0.912	1.218	1.177	0.08	1.90	6.81	4.39	+ 4
2	116	48.3	0.899	0.912	1.199	1.163	0.12	1.33	6.77	2.46	+ 2
3	140	48.8	0.899	0.908	1.198	1.159	0.094	1.84	6.40	3.01	-30
4	140	46.6	0.900	0.910	1.211	1.172	0.094	1.36	7.92	4.05	- 6
8	46.8	22.9	0.900	0.909	1.193	1.178	0.21	0.976	5.61	3.80	+ 0
7	87.6	21.7	0.896	0.908	1.199	1.186	0.38	1.21	6.43	2.62	+ 1
9	106	21.7	0.901	0.911	1.208	1.159	0.06	0.89	6.30	2.07	+ 4
9	122	21.9	0.908	0.916	1.211	1.165	0.16	1.25	7.46	1.85	- 5
10	139	23.1	0.904	0.911	1.207	1.167	0.19	1.09	7.24	1.60	+ 4

(a) $\frac{\text{Solute lost by water minus solute gained by alcohol}}{\text{Average amount transferred}} \times 100$

TABLE 1 (cont.)

RUN	% Cl IN WATER PHASE		$K_A a$	$(HTU)_{OA}$	$K_W a$	$(HTU)_{OW}$
	In	Out	#/hr.-cu.ft.-#/cu.ft.	Ft.	#/hr.-cu.ft.-#/cu.ft.	Ft.
1	29.8	30.5	20	4.8	3.4	14
1R	29.9	27.9	16	5.4	4.0	20
5	27.5	28.5	21	4.3	6.0	8.2
11	31.3	29.6	26	4.0	9.9	5.4
2	30.8	28.1	27	3.1	12	3.6
3	30.0	27.1	28	3.7	9.3	4.9
4	28.7	28.4	20	5.0	8.9	5.2
8	29.3	28.0	8.7	5.6	2.8	9.2
7	30.3	28.9	20	4.4	3.1	7.0
8	30.6	29.1	13	5.9	3.3	4.0
9	29.9	30.2	27	4.5	9.1	2.4
10	30.0	29.8	29	4.5	9.8	2.4

TABLE 2

RUN	FLOW RATE		SPECIFIC GRAVITY				CONCENTRATIONS #/ cu.ft.							
	cu.ft/hr.-sq.ft.		Alcohol		Water									
	Alcohol Phase	Water Phase	In	Out	In	Out	Water In		Water Out		Alcohol In		Alcohol Out	
							$NiCl_2$	$CoCl_2$	$NiCl_2$	$CoCl_2$	$NiCl_2$	$CoCl_2$	$NiCl_2$	$CoCl_2$
12	42.5	49.2	0.900	0.896	1.205	1.200	3.22	3.76	3.21	3.08	0.00	0.11	0.002	0.720
13	80.6	50.7	0.900	0.899	1.205	1.195	3.22	3.76	3.24	2.43	0.00	0.11	0.003	0.793
16	82.4	48.7	0.905	0.900	1.207	1.194	3.16	3.68	3.12	2.42	0.00	0.11	0.004	0.945
14	106	48.7	0.899	0.903	1.206	1.196	2.90	4.06	2.83	2.35	0.00	0.11	0.003	0.847
15	120	47.8	0.899	0.903	1.206	1.196	2.90	4.06	2.83	2.08	0.00	0.11	0.006	0.810
17	142	49.6	0.899	0.900	1.207	1.196	3.16	3.68	2.97	1.75	0.00	0.11	0.004	0.948
25	189	50.0	0.899	0.904	1.206	1.181	3.00	3.80	2.96	1.63	0.00	0.09	0.002	0.724
18	90.8	22.8	0.901	0.897	1.207	1.196	3.12	3.70	3.09	2.48	0.00	0.00	0.000	0.680
19	84.5	23.2	0.901	0.896	1.207	1.181	3.12	3.70	3.06	1.44	0.00	0.00	0.000	0.628
20	120	23.5	0.897	0.892	1.200	1.173	3.06	3.62	2.90	0.63	0.00	0.02	0.003	0.826
21	147	23.6	0.905	0.899	1.201	1.168	3.03	3.66	2.89	0.61	0.00	0.01	0.004	0.542
22	169	23.6	0.898	0.900	1.204	1.172	3.07	3.67	2.97	0.67	0.00	0.01	0.006	0.497

Results

Experimental data and calculated results are recorded in Tables 1-3. Table 1 summarizes the Series I runs where only $CoCl_2$ was the dissolved salt in the water phase whereas the Series II runs, involving the presence of $NiCl_2$ and $CoCl_2$, are summarized in Table 2.

Plots of $K_A a$ and $K_W a$ vs. the dispersed alcohol phase flow rate are given in Figures 4 and 5. The curves of Figure 4 are for the continuous water phase rate held within the limits 21.7 to 23.6 cu.ft./(hr.)(sq.ft.) while those of Figure 5 are for water phase rates from 43.3 to 50.7 cu.ft./(hr.)(sq.ft.). Corresponding sets of plots for $(H.T.U.)_{OA}$ and $(H.T.U.)_{OW}$ are presented in Fig-

ures 6 and 7. It is interesting to note that the points for both the cobalt and nickel-cobalt runs lie on the same curve, indicating that the rate of $CoCl_2$ transfer is unaffected by its replacement by $NiCl_2$, within the concentration limits investigated.

With few exceptions, the $CoCl_2$ material balances agreed within 10% total deviation.

No calculations of $NiCl_2$ transfer rates were made since essentially none of this salt was transferred.

Runs 4 and 23 were made at rates sufficiently high to approach the practical operating limits of the column. The operation was characterized by the collection of alcohol drops in the conical section at and below the point of attachment to the main length of the extraction tower to such an extent as to interfere with proper drop formation from the jets issuing from the disperser. This resulted in nonuniformly sized alcohol drops which were often as large as ½ in.

Although no direct use was made of the surface and interfacial tension measurements, these data are included to provide information on an additional physical property of the systems used.

TABLE 2 (cont.)

RUN	% TOTAL DEVIATION (a) IN INDIVIDUAL BALANCES	% Cl IN RAFFINATE PHASE Bz	Cyc	$K_A a$ lb./hr.-cu.ft.-lb./cu.ft.	$(HTU)_{OA}$ Ft.	$K_W a$ lb./hr.-cu.ft.-lb./cu.ft.	$(HTU)_{OW}$ Ft.
12	+ 22	28.6	29.3	7.1	6.0	3.8	20
13	+ 19	28.6	28.3	18	4.3	6.1	6.3
16	- 12	29.0	28.2	24	3.4	7.8	6.2
14	+ 7	29.1	28.5	22	4.3	7.6	6.6
15	- 1	29.1	28.3	20	4.0	10	4.8
17	- 8	29.0	28.4	29	3.6	9.7	6.1
22	+ 8	28.3	28.7	40	4.0	6.8	8.8
18	0	29.1	28.2	7.8	6.6	3.6	6.8
10	+ 9	29.3	28.1	10	8.8	8.8	6.1
20	+ 9	28.5	28.8	31	4.2	17	1.4
21	- 6	28.4	27.4	27	4.0	16	1.6
22	- 6	28.2	28.0	36	4.7	13	1.8

(a) $\frac{\text{Solute lost by water minus solute gained by alcohol}}{\text{Average amount transferred}} \times 100$

TABLE 3

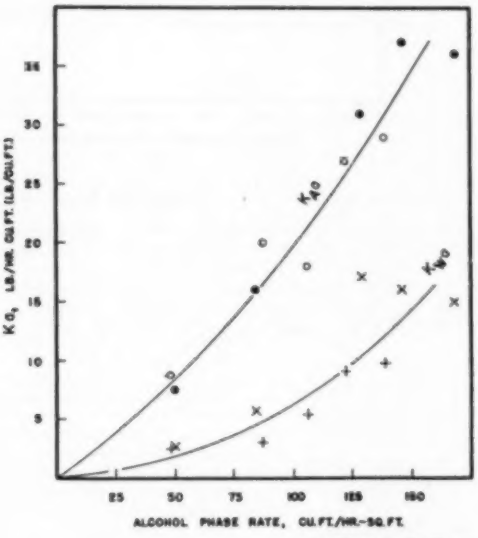
Surface and Interfacial Tensions - Temperature 86 to 90°F.

Surface Tension

Solvent, run 22	28.6 dynes/cm.
Extract, run 22	28.7
Extract, run 23	28.7
Raffinate, Run 22	27

Interfacial Tension

Solvent, run 14 / Aqueous feed, run 14	Equal volumes equilibrated	2.6 dynes/cm.
Solvent, run 14 / Raffinate, run 14	Equal volumes equilibrated	2.6
Extract, run 22 / Aqueous Solution, 8% $CoCl_2$, 20% HCl	Equal volumes equilibrated	3.4



▲ Fig. 4. $CoCl_2$ extraction coefficients. Water phase rate 21.7-23.6 cu.ft./(hr.) (sq.ft.)

Series I $K_A a$ 0 $K_W a$ +
Series II $K_A a$ ● $K_W a$ ×

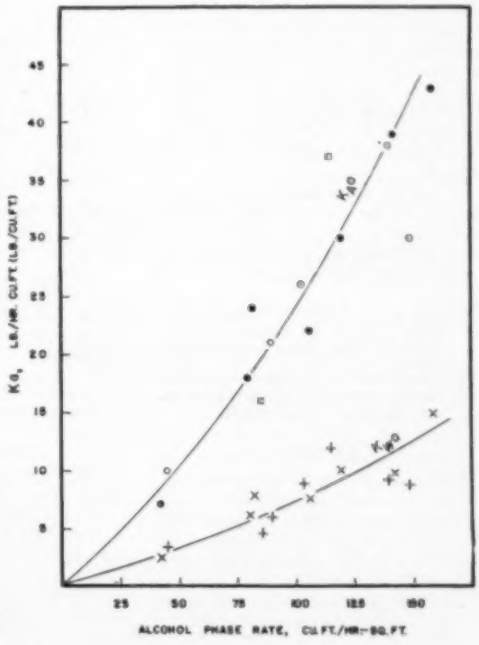
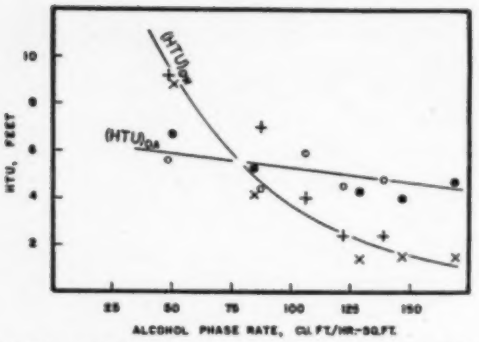


Fig. 5. $CoCl_2$ extraction coefficients. Water phase rate 43.3-50.7 cu.ft./(hr.) (sq.ft.) ►

Series I $K_A a$ 0 $K_W a$ +
Series II $K_A a$ ● $K_W a$ ×

Conclusions

Results obtained indicate that the over-all *H.T.U.* values for the extraction of $CoCl_2$ from aqueous solutions by capryl alcohol in a spray tower are of the same order of magnitude as those for organic solutes extracted in similar equipment (*4, 5, 11, 13*).



▲ **Fig. 6. $CoCl_2$ extraction coefficients. Water phase rate 21.7-23.6 cu.ft./(hr.) (sq.ft.)**

Series I
$(HTU)_{OA}$ 0
$(HTU)_{OW}$ +

Series II
$(HTU)_{OA}$ ●
$(HTU)_{OW}$ ×

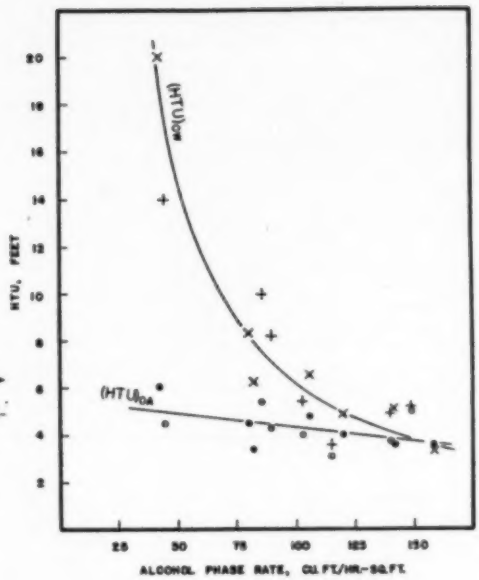


Fig. 7. $CoCl_2$ extraction coefficients. Water phase rate 43.3-50.7 cu.ft./(hr.) (sq.ft.) ▶

Series I
$(HTU)_{OA}$ 0
$(HTU)_{OW}$ +

Series II
$(HTU)_{OA}$ ●
$(HTU)_{OW}$ ×

For the runs made, the ratio of cobalt to nickel in the extract was, on the average, of the order of 200 to 1. This was obtained with about a 1.3:1 ratio of the salts in the feed, showing that considerable separation of these two salts can be obtained in an extraction tower operated under steady-state conditions. The fact that this separation is somewhat greater than the equilibrium separation appears to indicate a lower mass-transfer rate for the nickel than for the cobalt. The amount of nickel extracted is so small as to be subject to considerable error, however, and direct experimental verification would be difficult.

A simple preliminary design of a spray tower for the separation of nickel and cobalt by extraction with capryl alcohol is aided by two characteristics of the system observed:

1. The cobalt extraction capacity coefficients appear to be independent of the nickel-to-cobalt ratio in the aqueous phase.
2. The $(H.T.U.)_{OA}$ values for the cobalt extraction are approximately constant, varying from about 4 to 6 ft.

Notation

a = interfacial area per unit volume, sq.ft./cu.ft.
dA = differential interfacial area, sq.ft.
C = $CoCl_2$ concentration, lb./cu.ft.
$\Delta C_A = (C_A^* - C_A)$ at any point in the column, lb./cu.ft.
$\Delta C_W = (C_W - C_W^*)$ at any point in the column, lb./cu.ft.
D = distribution coefficient, (wt. % salt in the alcohol phase at equilibrium)/(wt. % salt in the water phase at equilibrium)
H = height, ft.
$H.T.U.$ = height of a transfer unit, ft.
K_A = extraction coefficient based on the alcohol phase, lb./(hr.)(sq.ft. of interfacial area)(ΔC)
Ka = extraction capacity coefficient, lb./(hr.)(cu.ft. of column)(ΔC)
L = liquid rate, (cu.ft.)/(hr.)(sq.ft.)
$MeCl_2$ = $CoCl_2 + NiCl_2$
N = rate of $CoCl_2$ transfer, lb./hr.
S = cross-sectional area of the column, sq.ft.
V = volume of the column, cu.ft.

SUBSCRIPTS:

A = alcohol phase
lm = log mean
OA = overall, based on alcohol phase
OW = overall, based on water phase
W = water phase
1 = top of column
2 = bottom of column

SUPERSCRIPT

$*$ = equilibrium value

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COMPRESSOR AND EXPANDER DESIGN

Temperature Change for Reversible Polytropic Paths

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Changes in temperature with changes in pressure may be calculated for reversible polytropic processes involving actual gases by an exponent presented in this paper. This exponent is a function of generalized properties, heat capacity and a newly defined adiabatic factor, which is determined by the amount and direction of heat flow.

The proposed method is demonstrated by computing temperature changes for 72 reversible polytropic paths of nine different gases and comparing the results with readings from tables or graphs of thermodynamic properties from the literature. Two alternate methods are presented for calculating the work of reversible polytropic processes. Both require the final temperature for the path.

BUT for one or both of two phenomena, the compression and expansion of gases would occur at constant entropy. These two phenomena are: the transfer of heat to or from the gas; and non-reversibility. These two characteristics may be encountered in any of four possible combinations: (a) adiabatic and reversible, (b) adiabatic and nonreversible, (c) nonadiabatic and reversible, and (d) nonadiabatic and nonreversible. The first of these four is the isentropic path. The others will be polytropic if the heat flow or the nonreversibility occurs in such a manner that a pressure-volume relationship of PV^n = constant is maintained. Thus an adiabatic path may be isentropic or polytropic depending upon whether or not it is reversible. Likewise, a nonadiabatic path may be reversible.

The departure of the actual compression or expansion process from the isentropic path might well be expressed in terms of two factors, a reversibility efficiency and an adiabatic factor. The reversibility efficiency, which is the ratio of the theoretical reversible work to actual work for compressors and the reciprocal of this ratio for expanders, must always be less than unity, as no actual process is completely reversible. Since heat may flow in either direction, to or from the gas, the proposed adiabatic factor may be greater or less than unity.

The objective of this paper is to develop a calculation method for estimating the final temperature for reversible and nonadiabatic (i.e., polytropic) compression and expansion of gases for which no Mollier charts exist. Deviations from reversibility are outside the scope of this article.

For a reversible polytropic path, heat will flow to or from the gas, the temperature and the enthalpy will change, and work will be done upon or by the gas, all these changes occurring in a definite relationship to one another. When only reversible mechanical work is involved, as is the case under consideration, the heat, work and enthalpy change relationship is given by the first law of thermodynamics

$$\Delta H = Q + \int V dP \qquad (1)$$

The ΔH term depends only on the terminal conditions while the heat and work terms depend upon the path followed. The $\int V dP$ term includes the net work of receiving and delivering the gas as well as compressing it.

For an adiabatic reversible process, where $Q = 0$, the work may be found from the value of ΔH but this is not true for nonadiabatic reversible paths, where it is necessary to know Q as well as ΔH in order to find the work from Equation (1).

The work for reversible polytropic paths may be found directly by integrating $\int V dP$ along a path

$$PV^n = const. \qquad (2)$$

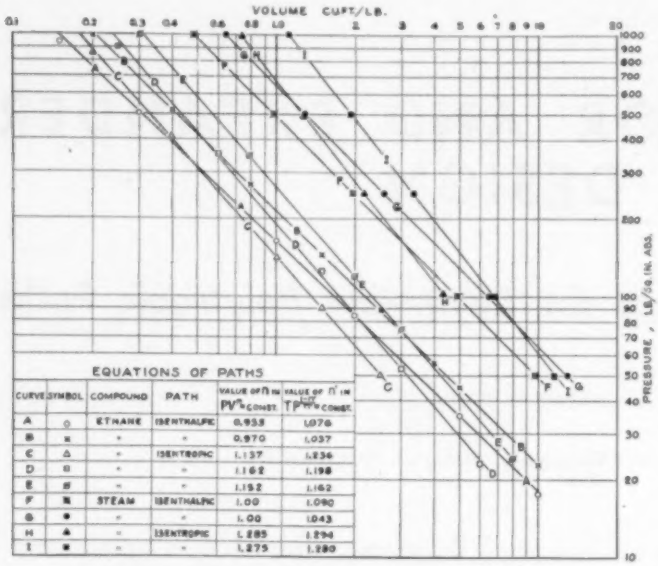
which gives

$$\int V dP = P_1 V_1 \frac{n}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] \qquad (3)$$

Equation (3) is valid for any path defined by Equation (2), regardless of the value of the exponent, for actual (nonperfect) gases as well as perfect gases.

There is a widespread misconception that Equation (3) depends upon the perfect gas law because it is often derived for perfect gas conditions. Equation (3) is not limited to perfect gases, but to the condition defined by Equation (2), which is a necessary and sufficient condition for validity of Equation (3) regardless of approach to perfect gas behavior.

NOTE: Complete data of Table 1 are on file with the American Documentation Institute (Document 3113), 1719 N Street, N.W., Washington, D. C. Copies obtainable by remitting $1.00 for microfilm or $1.00 for photoprints.



CURVE	SYMBOL	COMPOUND	PATH	VALUE OF n IN PV^n = CONST.	VALUE OF n' IN $TP^{\frac{n'-1}{n'}}$ = CONST.
A	○	ETHANE	ISENTHALPIC	0.955	1.070
B	×	"	"	0.970	1.037
C	△	"	ISENTROPIC	1.137	1.236
D	□	"	"	1.162	1.198
E	⊕	"	"	1.152	1.162
F	⊠	STEAM	ISENTHALPIC	1.00	1.090
G	●	"	"	1.00	1.043
H	▲	"	ISENTROPIC	1.285	1.294
I	✱	"	"	1.275	1.280

Fig. 1. Plot of data for isenthalpic and isentropic paths of steam and ethane.

With the proper values of the exponent, n, Equation (3) may be used for computing the work for all reversible compression or expansion paths, including isentropic as well as polytropic. In all applications of Equation (3) made in this investigation the P_1V_1 product is replaced by its equivalent $(ZRT)_1$ and the results obtained in B.t.u./lb.mole.

The following ratio is proposed as a measure of the nearness of a reversible path to adiabatic conditions:

$$e_a = \frac{\Delta H}{\int V dP} \qquad (4)$$

For isentropic paths this ratio is unity while it is zero for isenthalpic path. This ratio is greater than unity for the addition of heat during reversible compression and for the removal of heat during reversible expansion. It is less than unity for the removal of heat during reversible compression and for the addition of heat during reversible expansion. In other words, the ratio defined by Equation (4) is greater than unity when there is an increase in entropy and less than unity when there is a decrease in entropy during reversible gas compression, while the reverse is true for reversible expansion.

The final temperature for a polytropic compression or expansion path is required for itself and also for use in estimating ΔH for the path. A simple exponent expresses temperature change with pressure, as follows:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n'-1}{n'}} \qquad (5)$$

The temperature change exponent is primed to distinguish it from the volume change exponent appearing in Equation (2) and (3). The values of n and n' may be different for the same path for the same gas.

Edmister and McGarry (*4*) proposed methods of estimating temperature and enthalpy changes for isentropic processes of actual nonperfect gases, their enthalpy change procedure requiring terminal temperatures and pressures, the final temperature being estimated by an expression similar to Equation (5) with an exponent evaluated from generalized and specific properties. A similar method has been developed for polytropic temperature changes.

Changes in T and V with P. As just indicated, the calculation of heat and work quantities for reversible polytropic paths requires relationships based upon the changes in temperature and volume with changes in pressure. These changes are expressed by Equations (2) and (5), the first applying to the entire path and all portions thereof and the latter applying to the terminal conditions only.

These two equations are written in this manner purposely to emphasize the fact that only terminal values of T and P are of interest in the relationship between temperature and pressure, whereas intermediate values of V and P are of interest in the relationship between volume and pressure. Only terminal conditions are required in estimating the change in enthalpy for any process; the nature of the path is of no consequence.

The nature of the PV path followed between two sets of terminal conditions in the compression and expansion of gases has an effect on the work quantity found by evaluating $\int V dP$. The manner in which volume changes with pressure, in gas compression and expansion, is indicated in Figure 1. Figure 1 is a log-log plot of pressure vs. volume for isentropic and isenthalpic paths of steam and ethane. Data for making the plot were taken from thermodynamic properties compilations of Keenan and Keyes (*6*) for steam and of Barkelew, Valentine and Hurd (*2*) for ethane.

Referring to Figure 1, it will be noted that straight lines have been drawn through the points for both isenthalpic and isentropic paths. Straight lines on these scales are represented by Equation (*2*), for which the values of the exponent n are tabulated in the box on Figure 1, the values of the temperature change exponent, n', are also given for comparison. It will be noted that the temperature change exponent is always larger than the volume change exponent. Also the isentropic exponents are appreciably larger than the corresponding isenthalpic exponents.

With isenthalpic and isentropic PV data forming straight lines on those scales for both ethane and steam, it appears reasonable to postulate straight lines for the intermediate polytropic paths and also for similar paths of other substances. Equation (*2*) may be considered applicable over limited ranges and not generally applicable for the entire range of pressure covered by Mollier diagrams. However, the normal pressure ranges of compressors and expanders are well within the limits of validity of Equation (*2*).

Figures 2 and 3 are replots of indicator diagrams taken from the head end of a reciprocating compressor. These two diagrams are typical of several made available to the writer by Thiel (*12*). The two diagrams shown are for the same cylinder with different clearance volumes, the clearance pockets being closed in one case and open in the other.

The compressor indicator diagrams in Figure 2 are replotted on log-log scales in Figure 3 to illustrate the paths of the compression and expansion strokes on these scales and to show that Equation

(2) is applicable. The values of the exponent n are indicated on the plots. It will be noted that the exponents for the expansion stroke are of lower magnitude than the exponents for the corresponding compression stroke. For most of the indicator diagrams examined by the writer, the exponent for the expansion stroke was smaller than the exponent for the compression stroke. It will also be noted, by an examination of Figure 3, that the exponents are smaller on the diagram for the cylinder with the clearance pocket open. Although the value of the exponents for these paths are different the straightness of the line indicates that the value of n is constant for each path. Data represented on Figures 2 and 3 plus similar indicator card data justify the use of Equation (2) for polytropic compression and expansion paths.

The value of n in Equation (2) can be found for any polytropic path from terminal values of the pressure and specific volume, the latter being found from the terminal values of pressure and temperature. Thus, the volume change exponent is dependent upon the temperature change exponent.

Exponent Equations. For engineering design purposes, it is important that a rapid method of evaluating the exponents be available and that this method be generally applicable to all gases and gaseous mixtures, including those for which no thermodynamic compilations are available as well as those for which such properties have been published.

An equation for the isentropic temperature change of an actual gas is obtained by applying the restriction $dS = 0$ to the following entropy equation:

$$dS = \frac{C_P}{T}\,dT - \left(\frac{\partial V}{\partial T}\right)_P dP$$

and combining with the expression for the derivative in terms of compressibility factor, which is

$$\left(\frac{\partial V}{\partial T}\right)_P = \frac{R}{P}\left[Z + T\left(\frac{\partial Z}{\partial T}\right)_P\right]$$

The resulting equation is

$$C_P \frac{dT}{T} = R\left[Z + T\left(\frac{\partial Z}{\partial T}\right)_P\right]\frac{dP}{P} \qquad (6)$$

This equation was recently (*4*) integrated and a generalized expression for the exponent in Equation (5) obtained by assuming average values of the coefficients of dT/T and dP/P. This average exponent was shown to be a

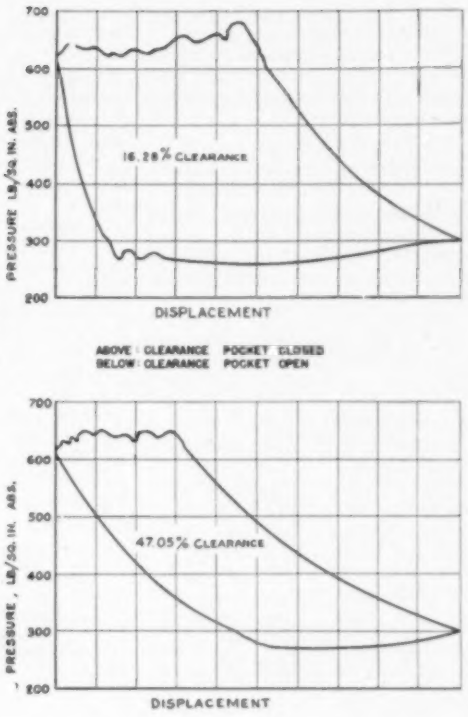


Fig. 2. Indicator diagrams for head end of Cooper - Bessemer compressor cylinder—Thiel (*10*)

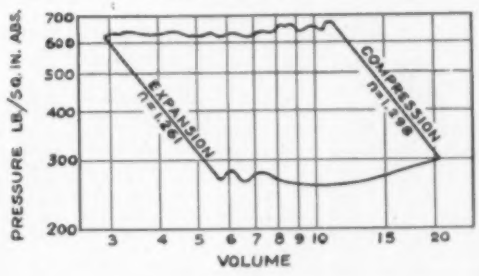
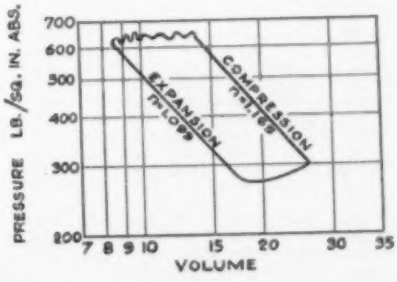


Fig. 3. Replot of compressor indicator diagrams shown in Fig. 2.

LOG-LOG PLOTS OF COMPRESSOR INDICATOR DIAGRAMS



reliable and accurate engineering tool for adiabatic and reversible paths.

In a similar manner, an analogous equation may be derived for the isenthalpic path. The fundamental equation for the enthalpy is

$$dH = C_p dT - \left[T\left(\frac{\partial V}{\partial T}\right)_p - V \right] dP$$

For constant enthalpy $dH = 0$. Making this restriction and replacing V and $(\partial V/\partial T)_p$ with their equivalents in terms of the compressibility factor, Z, gives

$$C_p \frac{dT}{T} = RT\left(\frac{\partial Z}{\partial T}\right)_p \frac{dP}{P} \qquad (7)$$

The similarity of Equations (6) and (7) suggests writing a single equation that applies to isentropic, isenthalpic, and all polytropic paths in between by using a factor defining the adiabatic nature of the path. This equation is

$$C_p \frac{dT}{T} = \left[RZe_a + RT\left(\frac{\partial Z}{\partial T}\right)_p \right] \frac{dP}{P} \qquad (8)$$

where e_a is the factor defining the adiabatic nature of the path. The symbol defined earlier by Equation (4) is used in Equation (8). There is no mathematical proof that these are identical. It is obvious by inspection, however, that the values of e_a in both equations will be unity for isentropic paths and zero for isenthalpic paths. It will be shown later, by numerical calculations, that e_a in Equation (8) is the same as e_a in Equation (4) for polytropic paths as well.

A rigorous integration of Equation (8) would be hopelessly complex because the coefficients of dT/T and dP/P are both functions of temperature and pressure. Even if such an integration could be accomplished, the result would probably not be in the form of Equation (5) but would be in a less practical form. Therefore Equation (8) is solved by using average values of the coefficients of both terms for the path, in the same manner Equation (6) was solved by Edmister and McGarry (4). This solution gives:

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\left[RZe_a + RT\left(\frac{\partial Z}{\partial T}\right)_p\right]}{C_P}} \qquad (9)$$

in generalized terms the exponent of Equation (5) becomes

$$\frac{n'-1}{n'} = \frac{RZe_a + RT_r\left(\frac{\partial Z}{\partial T_r}\right)P_r}{C_P^\circ + \Delta C_P} \qquad (10)$$

The exponent in Equation (9) and (10) is a point function of temperature pressure and the rate of heat removal or addition. The exponent is theoretically rigorous only for a path of infinitesimal length. It has been demonstrated (4) that using an average exponent is entirely satisfactory for isentropic paths. This average exponent technique has been extended to polytropic paths.

A more convenient expression than Equation (4) is desired for the adiabatic factor, e_a. Combining Equation (1) and (4) to eliminate ΔH gives

$$e_a = 1.0 + \frac{Q}{\int V dP} \qquad (11)$$

For the purpose of evaluating the adiabatic factor, e_a, it was found, by numerical calculations, that the $\int V dP$ term in Equation (11) could be replaced by a modified isothermal work expression, giving

$$e_a = 1.0 + \frac{Q}{(ZRT)_{ad.av} \ln P_2/P_1} \qquad (12)$$

TABLE 1 - PARTIAL TABULATION OF GENERALIZED THERMODYNAMIC PROPERTIES OF GASES FOR COMPRESSION AND EXPANSION CALCULATIONS

T_r	FUNCTION	VALUES OF FUNCTIONS FOR REDUCED PRESSURES OF R=1.0	1.4	1.8	2.2	2.6	3.0	3.5	4.0
1.00	ZR		0.460	0.550	0.650	0.745	0.830	0.940	1.050
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$		1.690	0.840	0.610	0.530	0.500	0.490	0.470
	ΔC_p		60.0	40.5	33.5	30.5	28.8	27.8	26.8
	$-\Delta H/T_c$		8.60	8.95	9.05	9.15	9.20	9.25	9.30
1.05	ZR	1.202		0.615	0.705	0.790	0.870	0.972	1.080
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$	4.428		3.185	1.295	0.890	0.730	0.638	0.580
	ΔC_p	15.6		34.5	28.5	25.2	23.0	21.2	19.9
	$-\Delta H/T_c$	2.820		6.95	7.40	7.70	7.90	8.00	8.05
1.10	ZR	1.378	1.070	0.820	0.800	0.846	0.913	1.005	1.110
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$	2.972	7.00	5.480	3.45	2.254	1.427	0.925	0.690
	ΔC_p	7.71	22.5	28.7	24.5	19.7	17.0	15.3	14.5
	$-\Delta H/T_c$	2.30	3.80	5.47	6.25	6.65	6.95	7.12	7.25
1.15	ZR	1.490	1.268	1.059	0.968	0.881	1.00	1.064	1.150
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$	2.200	3.772	5.141	3.982	2.469	2.00	1.286	0.920
	ΔC_p	5.22	11.80	19.30	20.00	15.10	14.10	12.60	11.80
	$-\Delta H/T_c$	1.978	3.05	4.24	5.20	6.00	6.10	6.40	6.60
1.20	ZR	1.577	1.408	1.258	1.142	1.100	1.097	1.142	1.213
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$	1.763	2.562	3.412	3.998	3.200	2.415	1.678	1.157
	ΔC_p	4.03	7.22	11.70	14.40	13.20	11.90	10.60	9.90
	$-\Delta H/T_c$	1.74	2.60	3.55	4.42	5.02	5.40	5.75	6.00
1.3	ZR	1.684	1.577	1.490	1.400	1.333	1.300	1.298	1.330
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$	1.246	1.749	2.200	2.610	2.917	2.850	2.272	1.770
	ΔC_p	2.71	4.27	6.10	7.75	8.80	9.25	8.90	8.20
	$-\Delta H/T_c$	1.395	2.02	2.70	3.35	4.00	4.45	4.90	5.19
1.4	ZR	1.769	1.688	1.620	1.565	1.521	1.490	1.477	1.490
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$	0.944	1.262	1.580	1.860	2.089	2.270	2.403	2.210
	ΔC_p	1.870	2.820	3.86	5.10	6.20	6.90	7.35	7.20
	$-\Delta H/T_c$	1.180	1.690	2.160	2.66	3.14	3.65	4.18	4.50
1.5	ZR	1.818	1.762	1.715	1.678	1.650	1.631	1.625	1.630
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$	0.612	0.868	1.105	1.312	1.468	1.569	1.655	1.670
	ΔC_p	1.370	2.030	2.75	3.56	4.42	5.15	5.73	5.95
	$-\Delta H/T_c$	1.008	1.410	1.810	2.220	2.62	3.02	3.45	3.80
1.6	ZR	1.850	1.809	1.771	1.742	1.720	1.708	1.700	1.706
	$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$	0.400	0.591	0.769	0.918	0.980	1.052	1.125	1.174
	ΔC_p	1.060	1.53	2.06	2.60	3.15	3.70	4.35	4.80
	$-\Delta H/T_c$	0.895	1.240	1.590	1.93	2.26	2.56	2.90	3.18

TABLE 2 - TERMINAL PRESSURES AND TEMPERATURES FOR PATHS USED IN DEMONSTRATION CALCULATIONS

SUBSTANCE AND REF.	OPERATION	GROUP	PRESSURES Lb./Sq. In. Abs. Initial	PRESSURES Lb./Sq. In. Abs. Final	TEMPERATURES °F. Initial	TEMPERATURES °F. Final Path C	TEMPERATURES °F. Final Path D	TEMPERATURES °F. Final Path E
H_2O (6)	Compression	I	500	2000	670	906	955	1000
	"	II	150	1300	400	800	985	1100
	Expansion	III	2000	500	955	660	570	470
	"	IV	1300	150	955	540	400	360
NH_3 (1)	Compression	I	28	100	180	280	347	390
	"	II	50	300	250	360	305	360
	Expansion	III	100	28	347	220	150	100
	"	IV	300	50	305	120	50	25
SO_2 (8)	Compression	I	200	1000	180	400	440	500
	"	II	60	300	200	370	446	500
	Expansion	III	1000	200	440	240	180	160
	"	IV	300	60	446	270	200	140
CH_4 (7)	Compression	I	80	400	-170	-60	-20	20
	"	II	80	250	-70	20	57	80
	Expansion	III	400	80	-20	-130	-170	-200
	"	IV	250	80	57	-30	-70	-100
C_2H_4 (11)	Compression	I	294	882	20	140	154	180
	"	II	147	735	100	240	290	340
	Expansion	III	882	294	154	40	20	0
	"	IV	735	147	290	160	100	80
C_2H_6 (2)	Compression	I	100	800	0	180	209	230
	"	II	100	500	220	340	377	410
	Expansion	III	800	100	209	50	0	-40
	"	IV	500	100	377	260	220	170
C_3H_8 (9)	Compression	I	100	260	171	270	297	340
	"	II	26	200	89	270	344	440
	Expansion	III	260	100	297	200	171	140
	"	IV	200	26	344	160	89	20
CCl_2F_2 (3)	Compression	I	36	200	100	200	230	260
	"	II	50	220	231	320	350	380
	Expansion	III	200	36	280	130	100	70
	"	IV	220	50	350	270	231	200
CHF_2Cl (5)	Compression	I	55	240	60	170	202	240
	"	II	50	260	200	320	366	400
	Expansion	III	240	56	202	100	60	30
	"	IV	260	50	366	250	200	160

where

$(ZRT)_{ad.av.}$ = average of terminal values of ZRT for adiabatic and reversible path (i.e., isentropic) having same initial conditions and final pressure as polytropic path in question

The justification of Equation (12) for finding values of e_a to use in Equation (9) is by numerical calculations that follow later.

In addition to the ideal gas state heat capacity, C_p^o, and the adiabatic factor, e_a, values of three thermodynamic functions are required in the solution of Equation (10) for the exponent n'.

These functions are: RZ, $RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$

and ΔC_p. Also values of $(-\Delta H/T_c)$ are required for the estimation of enthalpy differences. These five properties are generalized functions of reduced temperature and pressure. Edmister and McGarry (*4*) evaluated the derivative of Z with respect to T_c and tabulated

$$R\left[Z + T_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}\right], \Delta C_p$$

and $(-\Delta H/T_c)$.

In revising the previous (*4*) tabulation to include the functions required for polytropic calculations, it was deemed desirable to extend the temperature and pressure ranges. The resulting compilation is presented in Table 1. The sum of the first two of these terms, the

$$\left[RZ + RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}\right]$$

function is also plotted against reduced pressure for lines of constant reduced temperature on log-log scales in Figure 4. This combination was plotted in this way to supplement the previous plot. The ranges of T_r and P_r covered by Table 1 and Figure 4 are the recommended limits of the proposed method.

Application of Proposed Method

The procedure followed in applying the proposed method to reversible polytropic compression (or expansion) is outlined below and illustrated by sample calculations in Table 3.

Given: Initial and final pressures, the amount of heat added (or rejected) during the process and the initial temperature of the gas, for which critical temperature and pressure and the ideal gas state vapor heat capacities are known.

TABLE 3 - SAMPLE CALCULATIONS

	C_2H_6 Expansion				CH_4 at Compression			
		Final or Avge. for Path				Final or Avge. for Path		
H-S CHART OR TABLE DATA	Initial	C	D	E	Initial	C	D	E
Temperature, °F	377	260	200	170	89	270	344	440
Pressure, p.s.i.a.	500	100	100	100	26	200	200	200
Volume, cu. ft./lb.	0.5637	2.577	2.366	2.176	4.253	0.708	0.842	0.948
Enthalpy, Btu/lb.	597.7	540.9	520.2	495.4	212.98	245.02	264.50	290.52
n in $P_1/P_2 = (V_2/V_1)^n$		1.076	1.123	1.222		1.1375	1.2285	1.330
ΔH, Btu/lb. mole		-1707	-2330	-3075		1618	2602	3916
GENERALIZED DATA								
T_r		1.523	1.309	1.237	1.145	0.795	0.976	1.075	1.203
P_r		0.705	0.141	0.141	0.141	0.027	0.207	0.207	0.207
ZR		1.870	1.945	1.940	1.920	1.93	1.81	1.86	1.905
$RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$		0.38	0.165	0.180	0.230	0.16	0.59	0.43	0.295
C_p^o		17.55	15.60	14.96	14.13	9.85	11.60	12.28	13.20
ΔC_p		0.86	0.28	0.335	0.44	0.62	1.70	0.86	0.56
$C_p = C_p^o + \Delta C_p$		18.41	15.88	15.30	14.57	10.45	13.30	13.14	13.76
HEAT ADDED								
$\frac{(n-1)}{n}$			0.0706	0.1087	0.1824		0.1209	0.1827	0.248
$(P_2/P_1)^{\frac{n-1}{n}}$			0.8926	0.8395	0.7856		1.2796	1.452	1.658
$-W_s = \int v dP = Z_a RT_1 \frac{n}{n-1}\left[(P_2/P_1)^{\frac{n-1}{n}} - 1\right]$			-2380	-2312	-2184		2462	2622	2810
$Q = \Delta H + W_s$			+673	-18	-891		-834	-20	+1106
Q (adjusted)			+691	0	-909		-814	0	+1126
$-W_s$ (adjusted)			-2398	-2330	-2202		2932	2602	2790
ADIABATIC FACTOR								
Avg. Temp. for Adiabatic Path, °D			759	759	759		677	677	677
$(ZRT)_{Ad.Avg.} \ln P_2/P_1$			-2380	-2330	-2350		2618	2618	2618
$e_a = 1.0 + \frac{Q\ (calculated)}{(ZRT)_{Adiav} \ln P_2/P_1}$			0.703	1.0	1.390		0.688	1.0	1.430
e_a (obs.) = $\frac{\Delta H}{\int v dP}$			0.712	1.0	1.397		0.665	1.0	1.406
% Dev. of calc. e_a			-1.2	0	+0.5		+3.5	0	+1.9
FINAL TEMPERATURE								
$(ZR)_{av}$			1.908	1.905	1.895		1.87	1.895	1.918
$(ZR)_{av}\ e_a$ (calc.)			1.342	1.905	2.633		1.288	1.895	2.742
$\left[RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}\right]_{Av.}$			0.273	0.280	0.305		0.375	0.295	0.228
$\left[ZRe_a + RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}\right]$			1.615	2.185	2.938		1.663	2.190	2.970
$C_{p(av)}$			17.15	16.85	16.49		11.875	11.795	12.105
$\frac{n'-1}{n'} = \left\{[ZRe_a + RT_r(\frac{\partial Z}{\partial T_r})_{P_r}]/C_p\right\}_{av}$			0.0940	0.1296	0.1782		0.1400	0.1857	0.2453
$(P_2/P_1)^{\frac{n-1}{n}}$			0.8895	0.8418	0.7596		1.391	1.461	1.650
$T_{2calc.} = T_1\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 460$, °F.			259	219	169		271	342	446
ΔT calc., °F.			-118	-158	-209		182	253	357
ΔT obs., °F			-117	-157	-207		181	255	351
% Dev. of Calc. ΔT			0.8	0.3	1.5		0.6	-0.8	1.9

Find: Changes in temperature and enthalpy and the work for the resulting reversible polytropic path.

Polytropic Temperature Change

Preliminary Calculation Steps. By the procedure outlined by Edmister and McGarry (*4*), find the final temperature of the isentropic path between the given initial conditions and the final pressure. These calculations are a special case of the polytropic ones to be described here; a special case where $e_a = 1.0$. As pointed out previously (*4*), two trials are usually necessary because average values of the terms in the exponent of Equation (9) must be used so this requires estimating the final temperature so the values of C_p^o, ΔC_p, ZR and $RT_r\left(\frac{\partial Z}{\partial T_r}\right)_{P_r}$

may be evaluated and then checking this estimate.

Step 1. Knowing the final temperature of the corresponding isentropic path, the $(ZRT)_{av.\,ad.} \ln P_2/P_1$ term may be computed and e_a evaluated by Equation (12).

Step 2. Using the values of C_p^o, ΔC_p, RZ and $RT_r(\partial Z/\partial T_r)_{P_r}$ from the preliminary isentropic calculations and the value of e_a from, Step 1, find a "first-trial" value of $(n'-1)/n'$ from Equation (10).

Step 3. Using the exponent found in Step 2, estimate T_2 by Equation (5).

Step 4. Using the estimated value of T_2 from Step 2, find the final values of the terms C_p^o, ΔC_p, RZ and $RT_r(\partial Z/\partial T_r)_{P_r}$ and compute the average of the

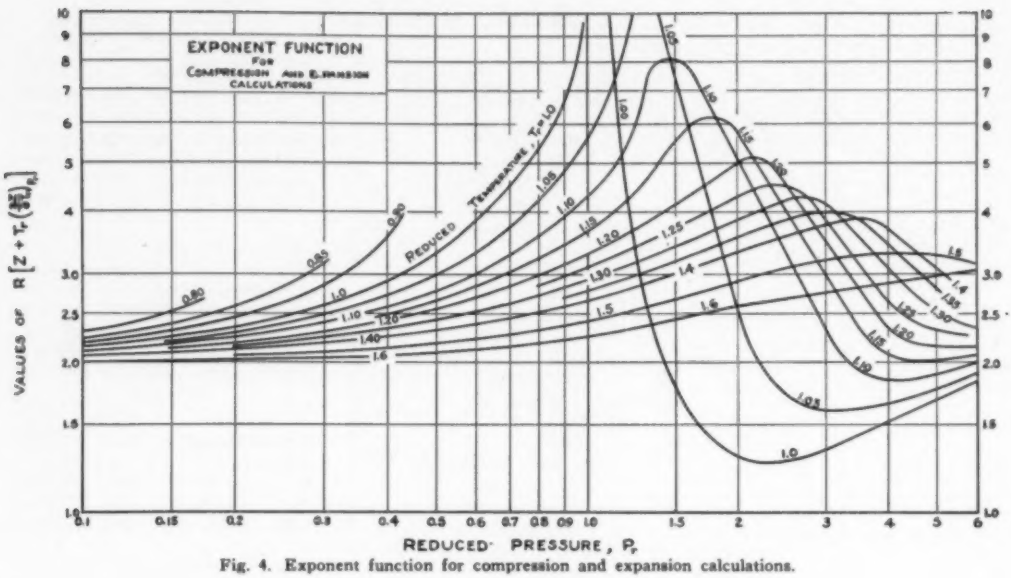


Fig. 4. Exponent function for compression and expansion calculations.

terminal values of these terms for the path in question.

Step 5. Recompute the exponent $(n'-1)/n'$ by Equation (10), using e_a from Step 1 and the average of the terminal values of the other terms.

Step 6. Using the new exponent from Step 5, compute final temperature of reversible polytropic path in question by Equation (5). If this temperature differs greatly from the value of T_2 found in Step 3 it may be necessary to repeat Steps 4, 5 and 6. This is not usually necessary however.

Polytropic Enthalpy Change

Step 1. Find ΔT for the path from above temperature change calculations.

Step 2. Find the mean value of Cp° for the path by averaging terminal values.

Step 3. Find $-\Delta H/T_c$ from Table 1 for terminal conditions, using reduced temperatures and pressures.

Step 4. Find ΔH for process from following equation:

$$\Delta H = C_p^\circ{}_{mean}\Delta T - T_c\left(\frac{-\Delta H_2}{T_c} - \frac{-\Delta H_1}{T_c}\right) \quad (13)$$

This is the same method used by Edmister and McGarry (*4*) for isentropic compression. The method is equally applicable to polytropic paths.

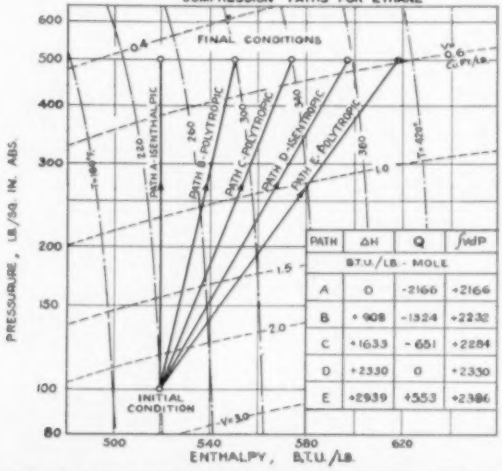
Polytropic Work Method No. 1

Knowing the values of Q and ΔH it is a simple matter to compute the reversible polytropic work by Equation (1).

Polytropic Work Method No. 2

Step 1. Knowing the initial and final conditions, assume Equation (2) applies to the path and evaluate the volume-change-with-pressure exponent n.

Step 2. Using this n value, solve Equation (3) for the reversible polytropic work.



PATH	ΔH	Q	fvdP
	B.T.U./LB.-MOLE		
A	0	-2166	+2166
B	+908	-1324	+2232
C	+1633	-651	+2284
D	+2330	0	+2330
E	+2939	+553	+2386

Fig. 5. Section of ethane pressure-enthalpy diagram illustrating selection of five compression paths for development and demonstration calculations.

Demonstration Calculations

Having justified the representation of polytropic paths between isenthalpic and isentropic by the relationship $PV^n =$ constant and having derived the equation for the exponent n' and developed the compilations of generalized thermodynamic properties required in estimating the exponent, it is next of interest to look at these various paths on pressure-enthalpy-type Mollier diagrams and to check the proposed exponent method with available information.

Figure 5 is a section of $P-H$ diagram for ethane with five compression

paths indicated thereon. Figure 6 is a similar graph showing five similar expansion paths. These paths are given the letters: *A*, *B*, *C* *D* and *E* for easy identification in the tabulations reporting the results of computations. It will be noted that the isentropic paths are the same in both compression and expansion plots. With the isenthalpic path as the lower limit and the isentropic path, from the same initial point, as a guide or reference line, three polytropic paths were selected so that two were between the isenthalpic and isentropic paths and one beyond the isentropic path. Readings of temperature, volume and enthalpy were taken at the terminal points of these paths for use in making demonstration calculations.

For each path shown on Figures 5 and 6, values of ΔH, Q and $\int V dP$ have been computed and are tabulated in the corner of the diagrams. It is of interest to note the variations in the values of ΔH and Q for the five paths and the near constancy of the $\int V dP$ values. From this it can be seen that serious errors would result from taking ΔH as the work for a polytropic path far removed from the isentropic path. It should be clear from the information on Figures 5 and 6 that Mollier charts alone are not adequate for calculating the polytropic work.

Terminal conditions were chosen in the manner represented by Figures 5 and 6 for paths *C*, *D*, and *E* of nine different substances, for which suitable compilations of thermodynamic properties were available in the literature. For each substance, two groups of compression paths and two groups of expansion paths were selected. Data obtained in this manner are tabulated in Table 2. This numerical work was limited to Paths *C*, *D*, and *E* because these are of the most practical interest. Rarely, in a reversible process, does the path fall outside this range.

Calculations, such as those shown in Table 3 for C_2H_6 expansion and CH_3Cl compression, were made for all the data given in Table 2. It will be noted that values of $\int V dP$ and Q were found by applying Equations (1) and (3) to the data read from the thermodynamic properties compilations and then adjusted to agreement with Path *D*, the isentropic path, for which $Q = 0$ and $\int V dP = \Delta H$, necessary conditions. These adjustments were always small, indicating the validity of Equations (2) and (3) for the isentropic paths. The necessity of these adjustments is due to imperfections in the calculations and/or $H - S$ compilations.

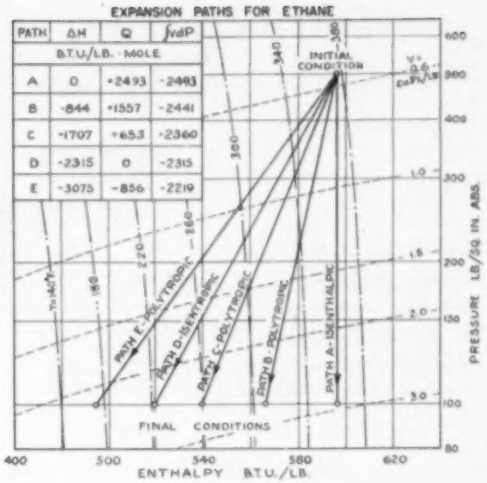

EXPANSION PATHS FOR ETHANE
PATH | ΔH | Q | ∫vdP
B.T.U./LB. - MOLE
A | 0 | +2493 | -2493
B | -844 | +1557 | -2441
C | -1707 | +653 | -2360
D | -2315 | 0 | -2315
E | -3075 | -856 | -2219
INITIAL CONDITION
V = 0.6 CU. FT./LB.
PATH E - POLYTROPIC
PATH D - ISENTROPIC
PATH C - POLYTROPIC
PATH B - POLYTROPIC
PATH A - ISENTHALPIC
FINAL CONDITIONS
PRESSURE LB./SQ. IN. ABS.
ENTHALPY B.T.U./LB.

Fig. 6. Section of ethane pressure-enthalpy diagram illustrating selection of five expansion paths for development and demonstration calculations.

TABLE 4 - DEMONSTRATION OF PROPOSED METHOD FOR CALCULATING POLYTROPIC TEMPERATURE CHANGES

Subst.	Operation	Group	Path C - Polytropic				Path D - Isentropic			Path E - Polytropic			
				ΔT °F		%	ΔT °F		%		ΔT °F		%
			C_n	Calc.	obs	Dev	Calc.	Obs.	Dev.	C_n	Calc	obs	Dev
H_2O	Compression	I	0.8197	340	330	3.0	391	385	1.6	1.1507	438	430	2.0
	"	II	0.7125	428	400	7.0	561	555	1.1	1.2680	715	700	2.1
	Expansion	III	0.612	-298	-295	1.0	-390	-385	1.3	1.537	-503	-485	3.7
	"	IV	0.621	-410	-415	-1.2	-559	-555	0.8	1.1110	-595	-595	0
NH_3	Compression	I	0.6750	132	130	1.6	195	197	-1.0	1.2185	240	240	0
	"	II	0.7756	196	200	-2.0	252	255	-1.1	1.2230	312	310	0.7
	Expansion	III	0.582	-123	-127	-3.2	-195	-197	-1.0	1.2936	-250	-247	1.2
	"	IV	0.628	-180	-185	-2.8	-254	-253	+0.4	1.1574	-281	-280	0.4
SO_2	Compression	I	0.778	246	220	11.8	276	260	6.2	1.322	324	320	1.2
	"	II	0.678	186	110	9.4	252	246	2.6	1.241	328	300	9.3
	Expansion	III	0.613	-218	-200	9.0	-272	-260	4.6	1.140	-290	-280	3.6
	"	IV	0.616	-182	-176	3.5	-258	-246	4.9	1.307	-313	-306	2.3
CH_4	Compression	I	0.6928	116	110	5.6	149	150	-0.6	1.288	188	190	-1.1
	"	II	0.784	95	90	5.6	127	127	0	1.188	157	150	4.6
	Expansion	III	0.5925	-111	-110	0.9	-150	-150	0	1.310	-176	-180	-2.2
	"	IV	0.660	-84	-87	-3.4	-127	-127	0	1.295	-156	-167	-6.6
C_2H_4	Compression	I	0.7866	114	120	-5.0	126	134	-6.0	1.421	182	180	-5.0
	"	II	0.6706	148	140	2.9	187	190	-1.6	1.337	233	240	-2.9
	Expansion	III	0.6682	-111	-114	-2.7	-128	-134	-4.6	1.349	-146	-154	-5.2
	"	IV	0.6810	-129	-130	-0.8	-188	-190	-1.1	1.137	-207	-210	-1.4
C_2H_6	Compression	I	0.7454	185	180	2.8	206	209	-1.4	1.146	231	230	0.5
	"	II	0.7295	124	120	3.4	158	157	0.6	1.237	188	190	-1.0
	Expansion	III	0.5950	-161	-150	1.3	-207	-209	-1.0	1.335	-241	-249	-3.2
	"	IV	0.7033	-118	-117	0.8	-158	-157	+0.6	1.390	-209	-207	1.0
CH_3Cl	Compression	I	0.7480	97	99	-2.0	122	126	-3.2	1.491	172	169	1.8
	"	II	0.6880	182	181	0.6	253	255	-0.8	1.436	357	351	1.9
	Expansion	III	0.6810	-93	-97	-4.0	-122	-126	-3.2	1.346	-152	-157	-3.2
	"	IV	0.6450	-180	-184	-2.2	-254	-255	-0.4	1.335	-329	-326	-1.5
CCl_2F_2	Compression	I	0.6960	97	100	-3.0	124	130	-4.6	1.309	155	160	-3.1
	"	II	0.6930	88	89	-1.1	115	119	-3.4	1.312	146	149	-1.9
	Expansion	III	0.6730	-97	-100	-3.0	-125	-130	-3.8	1.308	-150	-160	-6.2
	"	IV	0.6730	-77	-80	-3.8	-116	-119	-2.5	1.326	-145	-150	-3.4
$CHClF_2$	Compression	I	0.701	105	110	-4.6	135	142	-5.0	1.350	174	180	-3.3
	"	II	0.681	122	120	1.7	167	166	0.6	1.223	200	200	0
	Expansion	III	0.611	-109	-102	4.9	-136	-142	-4.2	1.284	-161	-172	-6.9
	"	IV	0.565	-107	-116	-7.8	-167	-166	0.6	1.352	-212	-216	-1.8

TABLE 5 - AGREEMENT OF CALCULATED VALUES FOR REVERSIBLE POLYTROPIC COMPRESSION AND EXPANSION BY PROPOSED METHOD WITH VALUES FROM H-S TABLES AND DIAGRAMS

	ADIABATIC FACTOR		TEMPERATURE CHANGE			ENTHALPY CHANGE		
	C	E	C	D	E	C	D	E
Total Number of Paths	36	36	36	36	36	36	36	36
Average Deviation, %	2.5	1.1	3.5	2.1	2.5	3.5	3.3	2.8
Positive Deviations	17	16	19	12	17	25	24	19
Average Positive Deviation, %	1.9	1.0	4.0	2.1	2.1	2.5	2.6	2.5
Negative Deviations	19	20	17	24	19	11	12	17
Average Negative Deviation, %	3.1	1.1	2.9	2.1	2.8	5.7	4.9	3.1

In these calculations two values of e_a were found, the one by Equation (4) being called the "observed" adiabatic factor while the one by Equation (12) is called the "calculated" adiabatic factor. The latter value of e_a was used in computing the exponents (via Equation (10) for calculating the final temperatures.

Observed and calculated values of e_a and ΔT are compared by finding the percentage deviations of the calculated from the observed values.

Results of these temperature change calculations are summarized in Table 4, where values of e_a are given for Paths C and E ($e_a = 1.0$ for Path D), and both observed and calculated values of ΔT are given for all paths. The percentage deviations of calculated from observed ΔT values are also shown.

In Table 5 the agreement of the proposed temperature change calculation method is shown by average deviations for each of the three paths. It will be noted that the agreement is better for Path D than for either C or E. This indicates that the arithmetic average exponent is better for Path D than for C and E.

The agreement of the enthalpy change method, given by Equation (13), for these same paths is also summarized in Table 5. It will be noted that this method is as good for Paths C and E as it is for D.

In addition to these, the agreement of calculated values of adiabatic factor from Equation (12) with the observed adiabatic factor from Equation (4) is also given in Table 5.

Comment and Conclusion

The proposed method of calculating the temperature change and the work for reversible polytropic compression and expansion is based on the use of an exponent that is a function of three generalized thermodynamic functions, the ideal gas state vapor heat capacity and a newly defined adiabatic factor. This adiabatic factor is shown to be a simple function of Q, the heat added during the process to make the path nonadiabatic.

For reversible and nonadiabatic machines, the polytropic path may be established by one of the following: (a) quantity of heat flowing, (b) final temperature, (c) the amount of work done, or (d) the adiabatic factor.

If the process is also nonreversible, one additional condition must be specified in order to define the path. The most effective and convenient way of specifying deviations from reversibility is by means of a reversibility efficiency, which would be the ratio of actual work done to the value of $\int V dP$ for compressors and the reciprocal of the ratio for expanders.

The exponent method of making compression and expansion calculations has the advantages of convenience and similarity with well-established but inaccurate calculation methods to recommend it for process engineering design purposes over the fundamental entropy-balance, energy-balance alternates. Most design engineers are of such a nature that they will continue using the exponent technique, even if they must guess the value of the exponent, rather than adopt a more tedious procedure of questionable increased precision.

Although the proposed method has been demonstrated only for pure compounds in this investigation, the method is suggested for mixtures, the techniques of application being the pseudocritical concept. For mixtures, as for pure compounds, the proposed method may be used as a preliminary estimating procedure before making the more precise and tedious entropy-balance, energy-balance computations.

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THE UNIFORMITY OF FLUIDIZATION—ITS MEASUREMENT AND USE

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UNIFORMITY of fluidization in boiling beds is a subject whose importance, as judged from the literature, has only recently been realized by many investigators of fluidized-solid processes. Research on the cause of differences in the results secured at various scales some time ago directed the authors' attention to nonuniformity of fluidization as an important cause.

Uniformity of Boiling Beds. The term, "uniformity of fluidization," describes the dispersion of particles and fluid in fluidized-solid suspensions (boiling beds) and replaces the previous term quality of fluidization (*8*). Liquid-fluidized beds of small particles approach perfect uniformity, for the particles appear to be distributed individually and rather uniformly through the liquid, which rises with nearly equal velocity at all points in the cross section. If the bed were perfectly uniform, the particles would be spaced equidistant from one another, and the fluid would have a flat velocity front.

The degree of uniformity depends upon the characteristics of the particles and the fluid, and also upon the design of the containing vessel. Gas-fluidized beds are commonly nonuniform, for segregation of particles from fluid quickly causes the gas to rise mainly in channels or pockets (bubbles), and the particles to circulate as flocs or aggregates. It has been shown (*8*) that the segregation tendency is a rate process and is balanced against a remixing process. For certain small particles, nonuniformity takes the form of flocculation of the particles into porous, transient clumps averaging several times the diameter of the particles. This flocculation is caused, it is believed, by interparticle attractive forces, and is therefore most noticeable for the smallest particles. The clumps are well distributed throughout the bed. The comparatively smooth boiling of the bed would suggest that the range of gas velocities is not wide.

As particle size increases, the flocculation tendency decreases but is gradually replaced by another effect, aggregation of the particles by Bernouilli forces (*1*). The aggregation leaves channels and bubbles in which the gas flows in a highly irregular and nonuniform manner. The aggregates are temporary, commonly being largest when they are descending in the regions of low gas velocity, and smallest when being conveyed on jets or in channels through the bed. (However, in the slugging bed, the large (column-size) clumps are lifted by the gas, then break and fall through the gas pocket as small clumps.)

Summarizing this description of boiling beds, uniformity of fluidization is characterized by well-distributed particles forming fluid passages of uniform resistance, making fluid velocity also uniform across the cross section. Nonuniformity of fluidization is characterized by flocs or aggregates of particles boiling or being conveyed by fluid that flows primarily in the pockets or channels between clumps, so that fluid velocities vary widely from point to point and from moment to moment.

Uniformity of Fluidization and Reactor Performance. Gaseous processes utilizing fluidized beds commonly can combine several reactions, depending upon conditions. One such combination is that of the desired reaction taking place preferentially in some specific temperature range, while, in a slightly different temperature range, the relative rate of an undesirable reaction may become excessive. Another combination is that of a desirable reaction taking place on the catalytic surface simultaneously with an undesirable thermal reaction in the gas phase.

In the first case, precise control of temperature is necessary in order to secure the optimum balance of preferred over undesired reaction. The fluidized-solid technique has gone a long way toward securing this control in economical reactors, and where the optimum point is not too sensitive, such as in catalytic cracking, the control is adequate. However, for extremely sensitive processes, the fluidized-solid technique in its crude form has not in all instances given adequate control. It has been suggested that in some of these cases the temperature variations between gas in the pockets and gas in the aggregates, although not measurable by the ordinary slow-response thermocouples, may have been sufficient to cause reduction of yield.

In the second case, the catalytic surface on those particles caught within the aggregates is temporarily unavailable to the gas which by-passes through pockets or channels. As a result, time of residence that might have been used for carrying out the desired catalytic reaction is used instead for the undesired thermal reaction, thereby decreasing over-all yield.

The above analysis indicates that maximum uniformity of fluidization is important in securing maximum yield from a reactor. However, there is an important opposing factor to be considered; namely, heat-distribution rates. The basic advantage of the fluidized bed is the high rate of heat distribution from zone to zone, permitting localized hot spots to be rapidly dissipated. The high heat-distribution rate is due to the rapid circulation of the particles, and altering the system to secure near-perfect uniformity of fluidization would eliminate the cause of the particle circulation. A compromise must therefore be made between maximum uniformity of fluidization and maximum rate of heat distribution.

This compromise will be different for each system, for it must reflect the thermogenic character of the main and side reactions, their relative rates, their temperature coefficients, and economic factors such as the value of yield loss. Many references have been made in the literature to the importance of smoother fluidization—few have indicated need for higher mixing rates.

McCune and Wilhelm (*6*) in connection with fluidization of beta naphthol beads in water, observed that:

> In highly expanded fluidized beds the particles congregated nearer the tube walls than the center. . . . Nonuniformities may be generated by tube walls or by other particles of a fluidized bed. . . . Nonuniformity as such is probably not the only consideration in explaining the mass transfer characteristics of a fluidized bed. It is likely that the scale and intensity of the liquid turbulence in the bed also will affect mass transfer rates and free settling velocity.

Goring (*3*), in interpreting his data on the reduction of carbon dioxide in high temperature fluidized beds of coke, observed that his bed was "characterized by bubbles of gas (dilute phase) rising through the solid (dense phase).

Data of Mason (*3*) indicate that the mixing between dense phase gas and dilute phase gas is insufficient to eliminate (transverse) partial pressure gradients at any given bed height."

Goring continued:

> The extreme case is described by no radial gas mixing and no gas flow through the dense phase, all the gas flowing upward in dilute phase. The only reacting solid would then be at the dense phase-dilute phase boundary, the dense-phase solid being rendered inert by surrounding gas at chemical equilibrium. In the actual case, both finite dense-phase gas flow and finite radial mixing occur, but the tendency is to concentrate CO in the dense phase resulting in two fluidization effects:
>
> (a) Effectively only a fraction (Goring's data show ⅕-½) of the total carbon present is in contact with oxidizing gas . . .
>
> (b) Radial partial pressure gradients are set up which tend to vitiate the 'piston flow' form of the rate equation.
>
> These effects highlight the present shortcomings of the fluidized bed technique as a laboratory tool for elucidation of reaction mechanism. Also, since the magnitude of the fluidization effects is probably a function of scale, the value of pilot data from a fluidized bed has definite limitations.

It should be apparent that the study of uniformity of fluidization is important. A fuller understanding will contribute greatly to rational design of fluidized-solid reactors and will, consequently, contribute to higher operating performance and lower costs.

Measurement of Uniformity of Fluidization. Observations in transparent or open-top vessels permit only an estimate of the superficial uniformity of fluidization. More thorough research requires semiquantitative investigation of the interior of the bed. Any device for such measurements must not affect the fluidization significantly and must be compact, versatile, convenient, rapid, and labor-saving. Its versatility must permit it to be used with a variety of materials, in a variety of vessels, and over a range of physical conditions.

Uniformity must be measured over a zone of appropriate size. If the zone is large compared to the scale of the clumps and bubbles, their effect will be averaged out; on the other hand, if the zone size is similar to the particle size, even a perfectly uniform bed would appear nonuniform. Inspection suggests that a cubical zone with ½-in. sides is appropriate for the common fluidized solids. Since the clumps and bubbles are moving and transient, the device must be able to respond instantaneously and continuously, and must produce some record of the result. The desirable instrument must therefore measure the mass of particles in a small zone of the bed instantly and continuously.

After consideration of several ways, use of the electrical capacity of a small electric condenser containing the material between its two plates was chosen. Implementing this method required the design and development of the special electronic unit described in the next section.

For a given arrangement of electrodes, the capacity of such a condenser is proportional to the mass and dielectric constant of the material between its plates. For the materials of common interest, the dielectric constant of the solid is considerably greater than that of the gas, and, consequently, replacement of any part of the gas by solid causes an increase in the capacity of the condenser. In fluidized beds there are two extremes of particle concentration, one being the settled bed, and the other the gas pocket. Any other situation falls between these extremes.

When the space between the plates is only partially full of material, the capacity probably depends upon the way the particles are arranged. This effect has been arbitrarily assumed negligible in this investigation.

Another factor to be considered is the effect of the probe on the bed conditions. It is obvious that any foreign object in the bed will tend to alter the fluidization uniformity—baffles are commonly introduced into beds specifically to break up clumps and thereby improve uniformity. Therefore, the probe must interfere as little as possible. In the work detailed below the probe consisted of small, thin plates, roughly ½-in. square, separated ¼-⅜ in., with vertical plane, and supported at the end of a ½-in. diameter tube. It is believed that little interference is caused by this type of probe on the material passing into and through the plates, although it may well be that distribution of the material downstream is affected by the probe.

A form of probe that has not yet been used experimentally consists of a single rod, perhaps ½-in. long by $\frac{1}{16}$-in. diameter, projecting from the end of the shielding tube—such a probe would be influenced strongly by the mass of material near it and exponentially less by the material farther away. Its simple form would presumably cause even less interference than the two small plates.

Device for Measuring Capacity Changes. Capacitive methods of measurement have been useful in measuring phenomena presenting difficulties by other known means (*5, 7*), but in the past the equipment was inflexible and expensive. However, with the development of frequency-modulation broadcasting, a measuring device sensitive to small capacitance changes can be quickly and cheaply constructed. Such a device was constructed in the Du Pont laboratory for measuring the properties of a fluidized bed. The device has been termed a "capacitometer." Its flexibility has been demonstrated by the simple expedient of changing electrodes (*4*).

An outstanding feature of the capacitometer is its ability to respond to rapid fluctuations in the measured quantity. Coupled to the proper type of instrument the indications or records are independent of the measurement frequency from zero to above 10,000 cycles/sec. Thus calibrations made in static beds may be applied without error to fluidized beds.

The capacitometer and its auxiliaries are shown in Figure 1 and the schematic diagram and parts list in Figure 2. The capacitometer consists of three main portions: (a) a vacuum tube oscillator whose frequency is determined by the inductance and capacitance, (b) a frequency-discriminator that translates the changes in oscillator frequency into corresponding changes of a d.c. voltage, and (c) a calibration reference unit for checking the tuning and drift of the capacitometer proper.

The oscillator's frequency is expressed by the relationship

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where f is the frequency in cycles/sec., L is the inductance in henries, and C is the capacity in farads. This capacity includes that of the probe, that of the tuning condenser, and various distributed capacities. The response of the discriminator to these changes in frequency follows the relationship shown qualitatively in Figure 3. Note that the output voltage passes through first a positive and then a negative peak. The part of the curve between the two peaks, near the zero crossing, is almost linear with respect to frequency. If the frequency excursions from the zero crossing are limited to about 100 kc., the response is linear within one or two per cent.

Inspection of the frequency-capacity relationship shows that the frequency varies inversely with the square root of capacity, which is not the desirable linear relationship. However, if the ratio of the capacity changes to the total capacity can be kept sufficiently small, the departure from linearity may be made negligible. A small ratio is achieved by having a large "padding" capacity in the oscillator circuit (100-500 times the capacity change) and using a correspondingly small inductance.

In the above manner, the capacity change occurring at the probe results in an essentially linear change in output voltage. The sensitivity of the unit described is approximately 1.5 $v./\mu\mu f$ for capacity changes of 1-5$\mu\mu f$, but can be varied by changing the L/C ratio of the oscillator.

A unit of such great sensitivity is liable also to the effects of other variables, such as temperature, relative humidity, and power supply voltage. The "drift" that results from these must be compensated for before any successful application is possible. This drift has been largely overcome in the following manner:

1. Thermal effects are largely overcome by the use of negative-temperature-coefficient capacitors. Thorough prewarming by application of the power several hours ahead of use also helps.

2. Moisture-absorption is minimized by winding the coils on polystyrene rods, and using high-quality, nonhygroscopic insulation.

3. Power-supply variations are overcome with the aid of voltage regulators, such as the Sorenson.

4. Variable power losses resulting from the material being studied are compensated for by the calibration procedure outlined later.

Details of the Capacitometer. A review of the requirements for making measurements in a fluidized column indicated a compact and lightweight unit because of the necessity of inserting the measuring probe in the experimental column in numerous positions. To this end all bulky or heavy refinements were discarded. As shown in Figure 2, the entire unit, including a power supply and calibrating system, is built into two connected $3 \times 4 \times 5$-in. sheet-steel boxes. An electron-coupled Hartley oscillator serves the triple purpose of oscillator, amplifier, and load decoupler. To conserve space germanium-crystal rectifiers are employed in preference to a vacuum-tube rectifier in the discriminator circuit. The required flexibility for altering the L/C ratio is obtained by winding several inductors of different values on ¾-in. polystyrene rods. Plug-in pins inserted in miniature jacks in the cabinet permit rapid change of inductors.

The tuning condenser verniers are made from 35-$\mu\mu f$ Isolantite insulated midget condensers by removing all but one rotor and one stator plate. Even with this reduced range, the adjustment of these condensers is somewhat critical.

The unit stripped of all but the most essential parts has sufficient stability for measurements up to a few hours in duration. When measurements extending over long periods of time were made the probe had to be removed from the bed for drift checking purposes. To obviate this difficulty a calibrating system was constructed in the lower box and secured to the original unit, which had consisted of only one box.

After its construction, the capacitometer requires discriminator adjustment similar to the detector alignment of an *FM* radio receiver. A calibrated grid dip meter or frequency meter is used to aid in adjusting the capacitometer oscillator to the designed frequency of 4.3 mc. by means of condenser C_6. The discriminator primary is then tuned with condenser C_7 to obtain a maximum output voltage. Next the discriminator secondary is tuned with condenser C_8 to reduce the output voltage nearly to zero. The adjustment procedure is repeated several times to refine the alignment. Finally the discriminator secondary is adjusted for zero output voltage.

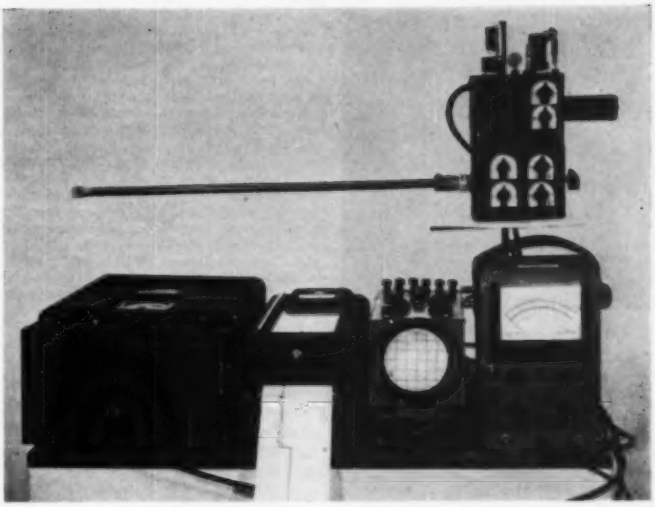

Fig. 1. Capacitometer and auxiliaries.

Faulty alignment or failure to use the discriminator transformer design frequency will result in a frequency-voltage output characteristic having little resemblance to the idealized curve of Figure 3. The unit described has been aligned only twice in more than two years.

Auxiliaries. Metering equipment consists of a vacuum-tube voltmeter for tuning and calibrating the capacitometer, an oscilloscope, for observing without recording the fluidization condition, and an oscillograph for securing the running record. The oscilloscope is convenient but not essential.

The oscilloscope required for this work must respond not only to the usual higher frequencies but also to the low frequencies and to direct current, for convenience in calibration and observation of drift. The Waterman Pocketscope, Model *S*-11-*A*, contains a d.c. amplifier and meets these requirements inexpensively. It is probable that the new Dumont Models 250-*A* and -*AH* would also be satisfactory.

Of the various types of oscillographs, the combination of the Brush *BL*-913 d.c. amplifier and the model *BL*-202 recording penmotor has been found satisfactory. It has uniform response from zero to approximately 100 cycles/sec., covering most of the range of frequencies encountered in fluidization work. It had advantages over photographing an oscilloscope trace in that a continuous and immediate record is obtained.

Probes. The original probe used in this work consisted of two plates on the end of a rigid coaxial cable. One plate was connected to the outer conductor which was bare and grounded. The other plate was attached to the inner, shielded conductor. This probe is illustrated on a photograph of the unit previously published (*4*). A later modification was made in order to shield the ungrounded plate from neighboring objects such as heat-transfer tubes. The modification consists simply in adding a third plate, grounded, on the side opposite the first grounded plate. Thereby the active field of the probe is greatly reduced. No effect on output voltage is produced by moving metal objects to within 2 in. of the edges of the plates, or zero distance normal to the plate faces. This probe is illustrated on the capacitometer (Fig. 1) and a close-up view of the tip is shown in Figure 4.

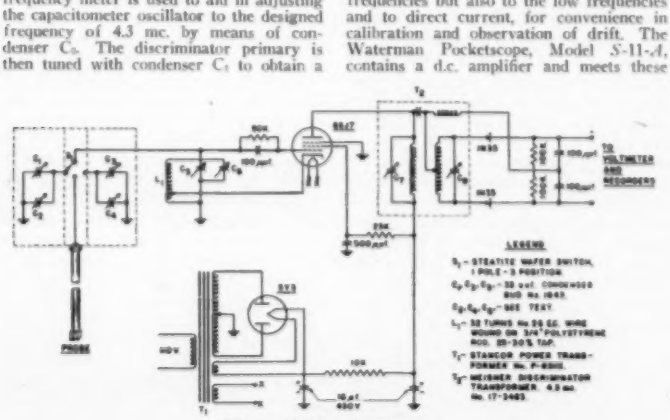

Fig. 2. Schematic diagram.

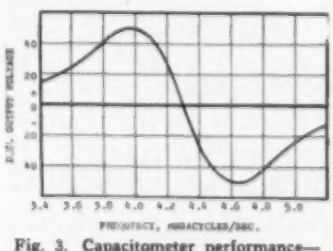

Fig. 3. Capacitometer performance—capacity vs. output voltage.

Fig. 4. Close-up view of probe.

Operation. For tuning and calibration prior to a run, it is desirable that the probe plates be bare.

With the selector switch in the probe position, the plates bare and the vernier tuning condenser in the mid-position, the capacity of the main tuning condenser is gradually increased until a marked change in voltage is noted. Continued gradual increase of capacity causes the voltage to pass through the positive or negative peak, decrease from the peak through zero to a peak of the opposite sign from the first, and then return toward zero, as illustrated in Figure 3. Having determined the position of the peaks, the capacity is adjusted to secure zero output voltage using the vernier tuning condenser and, for greater precision, a more sensitive scale on the voltmeter.

The next step is to switch the selector from the probe to the first reference unit, and adjust the main and vernier condensers to secure zero voltage again. Reference at the bare-plate voltage is thereby available for later check to determine or permit compensation for drift.

The plates are then covered with the material to be studied, establishing it at the desired condition either of tightly packed bed, or of loosely settled bed. (Both these conditions are somewhat difficult to duplicate, and there are arguments in favor of each. Currently the loosely settled bed is favored, both because it is presumed to represent approximately the condition of the clumps, and because it is more easily available for occasional reference during the course of a run without removing the probe, merely by slowly shutting off the gas flow to the bed, and allowing it to settle without vibration of the vessel.) With the selector switch in the probe position, the deflection voltage is noted equivalent to the settled bed between the plates.

In the fourth step, the selector switch is turned to the second reference unit, and its reference condensers tuned to secure the same voltmeter deflection as was caused by the bed. This operation completes the tuning and calibration of the capacitometer and permits it to be installed, with care not to disturb the tuning or reference units, in the vessel, if it is not already so installed.

Occasional checks for drift are made with the aid of the selector switch, and the capacitometer tuning or the amplifier gain is readjusted slightly if necessary. In general it has been found that the voltage differential does not change greatly during a run of several hours, although the zero may shift several per cent of the differential.

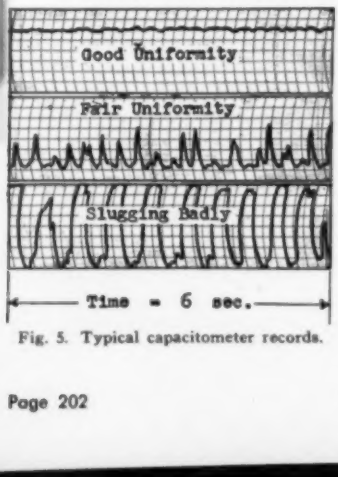

Fig. 5. Typical capacitometer records.

Results

Figure 5 shows a comparison of the capacitometer records for three typical materials. In each case, the horizontal axis is the time axis, 6 sec. being spread over the chart length, and the vertical axis is the capacitometer voltage. The upper margin indicates zero voltage, corresponding to open air between the plates (reference point 1) and the lower margin is the voltage corresponding to the settled bed. This voltage, of course, varies with the material, but the method of calibration makes all the charts directly comparable with respect to bed conditions, despite the material.

In the upper chart the record of a material that fluidizes outstandingly well is shown—an exceedingly fine, lightweight precipitated silica, similar to Santocel. The average level of the record indicates the average bed density in the region of the probe. For this material it was about 25% of that of the fixed bed, corresponding to a bed expansion of 300%. Smoothness of the line indicates that the uniformity of fluidization was high, for the variations in density were small compared with the average density.

The second record shows the uniformity of fluidization of a metal oxide catalyst under good conditions. The average value of the recorded line shows that the local density was about three fourths that of the settled bed, or a bed expansion of 33%. This recording is not nearly as uniform as the previous one, erratic variations in the density being shown. Visual observation with the probe near the glass vessel wall indicates clearly that such variations are due to passage of gas pockets between the plates of the probe. Duration of the low-density peaks indicates that the pockets are small. This record indicates fair uniformity of fluidization.

The lower record shows the uniformity of fluidization of the same material under unfavorable conditions. It will be noted particularly that the deviations from the average bed density are large both in magnitude and duration. Most of the peaks reach up to the zero-density axis. Most of the dips go down nearly to the settled bed axis. Many last as long as ½ sec.; this record is characteristic of a badly slugging bed, which is, of course, extremely nonuniform.

The authors' early work with this tool was carried out in small (3-4 in.) diameter glass columns so that observation of the condition of the bed was possible simultaneously with measurement of its fluidization condition. In every case the record and the observation agreed.

Uniformity Index. Records cited show three typical situations in fluidized beds. For more than a visual, qualitative comparison of these and other situations, it is desirable to reduce the oscillograph record to some numerical value characteristic of the record. Inspection of Figure 6 and the previous discussion will suggest that one important factor in such a numerical index would be the magnitude of the deviations. A small positive deviation is evidence of a small bubble that only partially empties the probe space. A small negative deviation is evidence of a small clump or floc of high-concentration material. A large positive deviation is evidence of a bubble that largely or completely clears the space between the plates. The reverse is also true—a large negative deviation is evidence of a large clump of particles completely filling the space between the plates.

The duration of any of these conditions is also important in establishing a numerical index. Obviously a condition of long duration is more important than one of short duration.

These two factors have been evaluated and combined into an arbitrary factor called a "Uniformity Index." The effect of the bubbles and clumps is obtained by calculation of the percentage of average deviation of the record.

The frequency factor is determined simply by counting (as complete cycles) the number of significant variations from uniformity over the given chart length, and expressing this as a frequency factor, deviations per second.

The two factors are combined empirically into the Uniformity Index by dividing the percentage average deviation by the deviation frequency. Inspection will indicate that this index must increase from zero for perfect uniformity to a large number for extreme nonuniformity. Table 1 summarizes the process of calculating this index.

For the calculations in Table 1 the planimeter was used to measure the curve areas. Although somewhat tedious, it is simple enough to be carried out by semiskilled technicians after brief training. If the amount of use

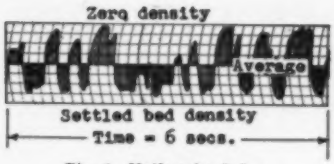

Fig. 6. Uniformity index.

justifies, it appears probable that electronic means could be developed to secure the desired result directly from the capacitometer output without the intermediate record.

Effect of Particle-Size Distribution. Many investigators have noted qualitatively that the uniformity of fluidization is better for mixtures of particle sizes than for narrow cuts. The capacitometer permits a quantitative comparison of different mixtures of sizes, thereby enabling precise selection of the optimum distribution.

In Figure 7 are shown sections from the capacitometer charts for two-size distributions of the same material. This material is the same metal oxide catalyst previously mentioned. Some of its properties are shown in Table 2.

A portion of the wide-cut material was screened to remove fines, the coarse residues being the narrow-cut fraction. The geometric size-distribution index (the log-geometric standard deviation) for these two materials is 4.6 and 1.0 respectively. A small change in average size resulted from the screening operation, but this does not seriously affect the comparison.

It is evident that the presence of fines greatly improves the uniformity of fluidization, their removal causing the uniformity index to rise from 3.8 to 32.

Effect of Gas Velocity. Charts shown in Figure 8 illustrate the effect of velocity upon uniformity of fluidization. The material under study was the wide-size range metal-oxide catalyst previously mentioned. At the lowest velocity shown, only slightly above the minimum fluidization velocity, the bed boiled moderately smoothly, giving a uniformity index of 2. Doubling the velocity trebled the uniformity index, the worsening taking place primarily as an increase in the size of the bubbles, with only a slight decrease in their frequency. This observation confirms remarks of previous investigators that after the minimum fluidization velocity is reached, additional quantities of gas pass through the bed as bubbles. However, it is believed that this observation must be restricted to coarse, heavy materials, fluidizing at high Reynolds numbers, for the fine materials have been seen to continue to expand rather uniformly over a wide range of velocity.

Increase of the velocity to three and one-half times the first velocity brought the bed to an incipient slugging condition, as is indicated by the presence of broad, irregular valleys and high rough plateaus on the record. The uniformity index reached 8.9, only a small increase from the previous index.

It should be noted that all the previous results were secured at the 6-in. level in a 30-in. expanded bed contained in a 4-in. diameter column. At this level the effect of the initially good gas distribution is still apparent, and the changes in velocity may make themselves evident. At the higher levels discussed in a section below, the effect of change in velocity is considerably obscured by the generally poorer uniformity of fluidization.

Effect of Initial Gas Distribution. In the previous section it was suggested that good gas distribution at the column

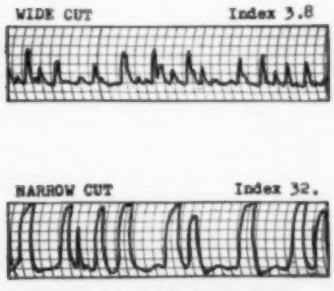

Fig. 7. Effect of size distribution.

TABLE 1.—UNIFORMITY MEASURES

$$\text{Av. density, \%} = \frac{\text{total area between curve and zero-density line} \times 100}{\text{total chart area}}$$

$$\text{Av. deviation, \%} = \frac{\text{total cross-hatched area} \times 100}{\text{total area between curve and zero-density line}}$$

$$\text{Frequency} = \tfrac{1}{2} \times \text{number of cross-hatched areas per second}$$

$$\text{Uniformity index} = \frac{\text{av. deviation, \%}}{\text{frequency}}$$

Experience has indicated the following ranges of the Uniformity Index:

Degree of Uniformity	Uniformity Index
High	<1.0
Fair	1.0-5.0
Poor, with increasingly large slugs	5.0-60.0

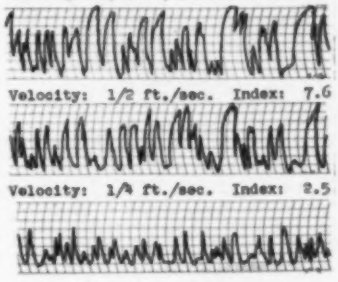

Fig. 8. Effect of gas velocity.

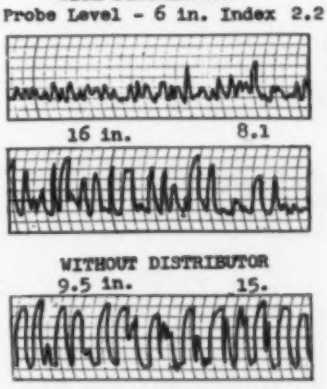

Fig. 9. Effect of initial gas distribution.

TABLE 2.—EFFECT OF PARTICLE-SIZE DISTRIBUTION

Material symbol		*A*		*B*	
Particle size cut		Wide		Narrow	
Uniformity index		3.8		32.	
Screen Analysis		% On	% Cum.	% On	% Cum.
48 mesh		26.8	26.8	36.1	36.1
65		17.8	44.5	25.1	61.2
100		16.6	61.2	23.5	84.7
150		10.1	71.3	12.2	96.9
200		6.7	78.0	3.2	100.1
270		3.7	81.7	....	....
pan		18.4	100.1	....	....
Geometric mean size, $d_g(2)$		0.185 mm.		0.245 mm.	
Size distribution index (log-geometric standard deviation, $O_g(2)$		4.6		1.	

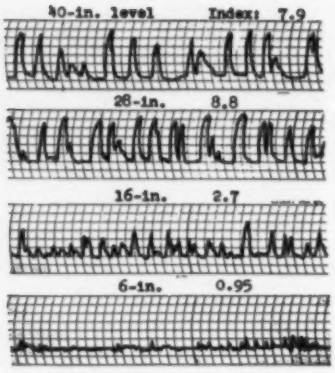

Fig. 10. Growth of slugs and pockets —Material A.

base may temporarily improve the uniformity of fluidization. This is confirmed in Figure 9. There in the upper and middle charts is shown the degree of uniformity at the 6-in. and 16-in. levels, above an initial gas distributor consisting of a piece of fine cloth sandwiched between coarse wire screens. In the lower chart is shown the degree of uniformity in the same column after removal of the screen. The probe is physically at the previous 6-in. level, but because of the addition of the cone bottom, the level is now 9.5 in. above the gas inlet.

It will be observed that use of the distributor improved uniformity for as much as 16 in. above the distributor.

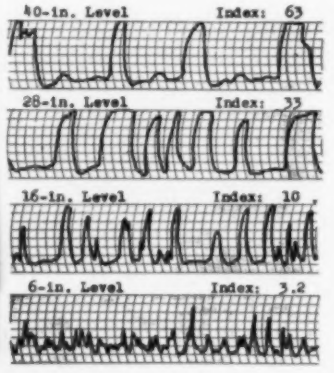

Fig. 11. Growth of slugs and pockets —Material B.

Other charts (not shown here) indicated that at higher levels the improvement was negligible or absent.

Effect of Bed Height. The effect on uniformity of increasing the height of the bed is a matter of concern in forecasting large-scale results from laboratory and pilot-plant investigations. There are two avenues for such an effect —first, the uniformity at higher levels may be different from that at lower levels, and second, an increase in bed depth may cause a change in the uniformity at some lower level. This section deals with the latter effect.

Table 3 shows the effect on the uniformity at the 6-in. level of deepening the bed above it by adding more material.

It is evident from Table 3 that the uniformity for Material *B* at low bed heights was not significantly affected by increasing the bed height by five times. The uniformity of Material *A*, the one that fluidized better, was significantly improved by deepening the bed.

Uniformity at Various Levels. The other effect that was suggested in the previous section is a possible change in uniformity from bottom to top of the bed at constant bed height. The evidence indicates that this effect is of large magnitude. Figures 10 and 11 show the results of traverses of beds of Materials *A* and *B*. Both figures show the rapid loss of uniformity as the probe level is raised from the bottom of the bed. The rate of change of uniformity is particularly striking; the material that inherently fluidizes poorly loses uniformity at much the greater rate. Figure 12 shows graphically the comparative rates of loss of uniformity for these materials with plots of considerable data in addition to those on Figures 10 and 11.

Discussion of Results

The majority of the work reported here was carried out on one material in two ranges of particle-size distribution. Work on other materials in general confirms the observations given here. It is believed wise not to use the information herein for extrapolation over large changes of scale, but rather to evaluate proposed materials with capacitometer and small-scale reactor tests covering the most critical factors of the particular development.

TABLE 3.—UNIFORMITY INDEX AT 6-IN. LEVEL

Material	Settled Bed Height			
	8 in.	16 in.	28 in.	40 in.
A—wide cut	2.3	2.2	1.7	1.2
B—narrow	3.7	3.7	2.5	2.2

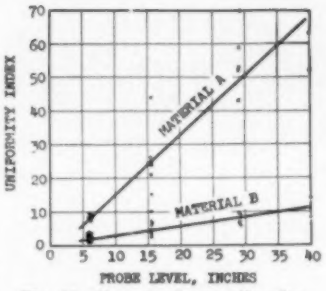

Fig. 12. Growth of nonuniformity.

A limitation in the field of application exists for this tool—materials of high electric conductivity such as metal powders and graphite cannot be tested as described, because any small bridge of conductive material from plate to plate amounts to an electric "short." Even insulation of the plates will not overcome this unless the material is low in conductivity, and does not form a fixed film on the insulated surface. Insulation of the plates has permitted study of certain charcoals, but has not sufficed for the study of graphite because its adherent conductive film on the insulated surface amounts to fixed third and fourth plates connected through the body of the bed, thereby constituting two fixed condensers connected by a varying resistance.

Summary

The capacitometer developed for the measurement of uniformity of fluidization provides a valuable tool for research and development in the fluidized-solid technique.

Acknowledgment

J. R. Caddell gave valuable assistance by carrying out and interpreting a large proportion of the tests reported.

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CHEMICAL ENGINEERING IN THE GLASS INDUSTRY

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GLASS is an article of commerce with which generally speaking, people are quite familiar. Since its production is one of the most ancient of industries, and natural glasses have been used from time immemorial, the desirability of tracing its complete history is doubtful. However, before getting into the mechanics and the art of glass-making, a review covering the last 50 years of the flat glass industry will serve as a suitable background for a study of the chemical engineering aspects of this product.

Previous to the present century, progress in the arts of glass manufacture had been sporadic and essentially inconsequential. Some mechanical processes had been introduced into the manufacture of plate glass, and automatic bottle machines had been developed. All sheet window glass was a handmade article. Production was largely seasonal in character and the workers were journeymen craftsmen. The industry was chaotic to say the least, both in the sheet window-glass and plate-glass fields. Multitudinous and ruinous competition was the order of the day and there were few if any funds available for development work of any kind—the producers were absolutely at the mercy of the buyers, whose cash advances were their only source of financial assistance.

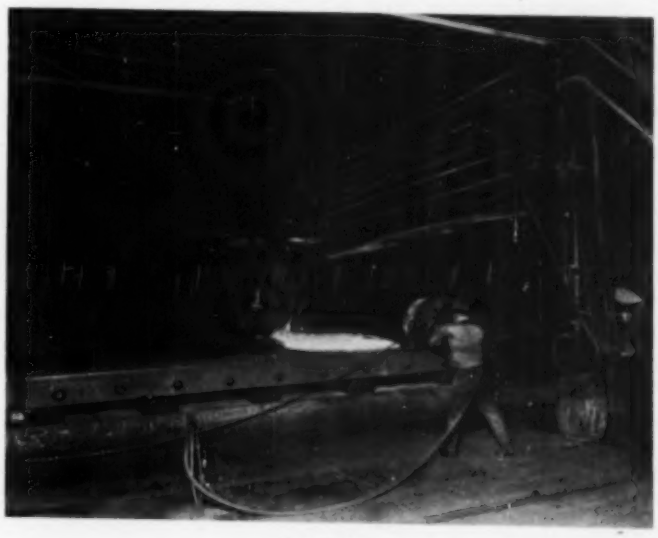
However, one cannot escape history even in the glass industry. The expanding economy of the nation required more glass—and developments in other fields, by typical though not so-styled chemical engineering processes were adapted to the production of glass. The Siemens open-hearth steel furnace was the progenitor of the modern glass-melting tank—Bessemer produced a continuous ribbon of glass—the hand-blown cylinder of window glass evolved into a cylinder-blowing machine of almost human capacity—and productivity was increased many-fold. This development brought with it a change in habit—seasonal production lagged, for the tank- and cylinder-blowing machine operated all the time so that the hand-blown window-glass plants which could compete neither in quantity, quality, nor cost gradually fell by the wayside and were practically extinct by 1929.

But developments seldom come singly. The machine cylinder process had hardly a good start when a method for producing a continuous flat-drawn sheet of window glass was invented in 1904 in the United States and a different but similar process for producing flat-drawn sheet glass was invented in Belgium at almost the same time. Neither became commercial until after 1929. The Owens bottle machine was developed during the preceding year, 1903.

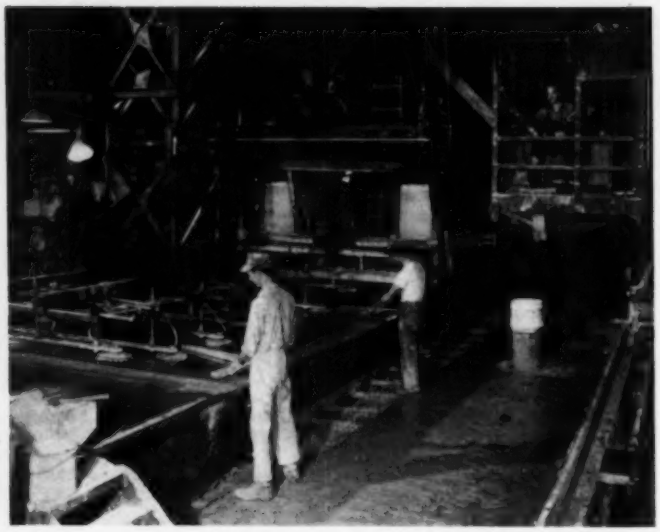
The development of the Colburn flat-drawn sheet window-glass process in the United States was rather slow and again was closely paralleled by the development of the Fourcault process in Europe but by 1929 both had become established processes, and a third process which is called the "Pennvernon" process was being developed. The machine cylinder process rendered obsolete almost before it began, did not disappear until a number of years later, but now virtually all sheet glass used is made by one of these three processes for producing flat-drawn sheet glass.

Meanwhile, American ingenuity and enterprise had not been idle in the ground and polished plate-glass field. Grinding had been accomplished by grading sand in a type of weir much like the panning of gold and the various grades of sand were dug out of their settling beds into wheelbarrows and fed to the grinders by hand. This was obviated by the invention of the Hitchcock sand-grading cone which classified the sand by a flotation process and separated the grades continuously so that they could be fed directly from the grader cone to the grinders in volume as required. Development of the so-called rod-lehr at about this same time, reduced annealing time and eliminated the old wasteful annealing oven kilns.

For many years, the plate-glass blanks were laid in plaster of paris on huge round tables, to be ground on one side.



Pot casting.



A modern laying yard.

They were then lifted and relaid to be ground on the second side. Again they were lifted and moved by hand from the grinding shed to the polishing shop, where the faces were successively polished. Some bright chemical engineer decided that this process was wasteful and persuaded some factory manager to let him put the grinding table on tracks, and then the glass need be laid only once to grind and polish each side. This cut grinding and polishing time almost in half—from 24 hrs. to 12 hrs.—with other developments to come.

The rod-lehr was followed quickly by the continuous motion roller lehr, which again cut annealing time, and itself led to the greatest advance in production techniques—the melting of plate glass in continuous tanks, forming the sheet between rolls at the delivery end, and its passage through a continuous roller lehr, to produce satisfactorily annealed glass, with an absolute minimum of loss.

The old round-table grinders and polishers gave way to a continuous train of grinding and polishing cars moving constantly forward under the grinders and polishers for first side finishing, to return to the laying yard for transfer to a second endless train for second side finish in similar manner. The two finishing lines—or G. & P. lines as they are called—are parallel tracks, and sand, emery and rouge are fed to both sides continuously as the work progresses.

The finished glass is now moved to the wareroom where it is examined for defects and marked for cutting as orders may require. A continuous conveyor moves the large marked sheets to the cutting machines where major longitudinal and transverse cuts are made as the glass moves forward to be finally lifted by the individual cutters and stacked on racks according to size.

The net result of these several improvements has been to reduce the elapsed time from raw material to finished glass from 190 hrs. to 15 hrs., and if the time in the annealing ovens or kilns is also taken into account, from 310 hrs. to 15 hrs.

Materials-Handling Equipment

Batch materials are received by rail and elevated into storage bins by endless belt elevators or by air streams. From the bins, they are delivered by gravity into the batch car, which in many instances is actually a rotary mixer, and if not to the mixer, where it is so thoroughly intermingled that segregation of ingredients becomes almost impossible. Another bucket conveyor now elevates the mixed batch to another storage bin above the batch hopper at the tank mouth or filling doghouse. This batch hopper is kept as nearly full of batch as may be practicable and a reciprocating mechanism feeds a blanket of batch continuously into the melting tank.

In a sense, this melting tank itself might be termed a piece of materials-handling equipment. It acts to convey molten glass to the working end, while finishing it on the way. It has been estimated that it requires approximately 8 hrs. to convert raw batch into finished molten glass delivered to the forming rolls.

Up to this point, the production of sheet window glass and plate glass follows the same pattern. Continuing with plate-glass processes, the glass is fed continuously from the mouth of the tank to the forming rolls, where the thickness and width of the ribbon are determined. The glass is prevented from squeezing out between the ends of the rolls by white hot metal guns which are fired with an explosive mixture of compressed air and gas. The spacing of these guns determines the width of the ribbon.

As it leaves the forming rolls, the ribbon of glass is picked up by the apron rolls of the continuous roll conveyor lehr. These rolls run just a bit faster than the forming rolls and thus slightly stretch the still semi-molten ribbon. The forming rolls make a "crust" on the ribbon which is still soft enough to break through if the glass were not moved away a trifle faster than it arrives.

Annealing time of course depends upon the thickness of the ribbon, and this determines the speed of draw. The speed must be just fast enough so that the glass may have reached a temperature of about 200° F. from a temperature of about 1700° as it left the rolls. About 200° are lost in the first 5 ft., and the rest in the 400-ft. lehr, rather rapidly from 1500° F. to 1150° F., slowly through the annealing range from 1150° F. to 950° F. and again rapidly to room temperature, or at least a temperature at which it may be handled.

At the lehr mouth, the rough glass is examined for any inclusions or defects which might render it unsuitable for grinding, and only full-size grinder blanks are cut from the ribbon. The rest is called cullet and is returned to the batchhouse, where it forms about 25% of the mixed batch. The grinder blanks are lifted on vacuum-cup-equipped frames manipulated from an overhead crane, and moved to storage racks, or are delivered directly to a lateral conveyor which moves the glass to the laying yard.

At the laying yard, another crane equipped with vacuum-cup frames and a turnover hairpin mechanism lifts the glass and deposits it in a bed of plaster of paris which has already been spread on the deck. A set of rollers is now brought to bear on the plate, and presses it down into the liquid plaster, squeezing out excess plaster and air as the rolls move forward over the plate.

Plaster in carload lots is stored in bins just as with batch materials. It is fed from these bins to a bucket elevator, then to a worm conveyor, which feeds the dry plaster to small storage bins at the laying yard (a travel of about 300 ft.) and at the middle yard (about 400 ft. farther). It is mixed with water by hand and the mixture is spread on the deck from an ordinary garden variety of sprinkling can. The mix is thin, but none the less sets up sufficiently in the short time allowed—less than 10 min.—to hold the glass securely to the decks as it passes under the grinder runners.

Grinding Plate Glass

Grinding is accomplished by crushing progressively finer grains of sand between the cast-iron shod grinder heads and the glass. The sand is supplied in water suspension to the center of each grinder head, directly and continuously from the sand-grader cone. The coarse sand is drawn from the bottom of the cone and fine grades at higher and higher positions, which vary slightly with changing seasons and water densities. Used sand is returned to a main sump and recirculated through the grader. Rough sand is dug from the bottom of the river or from more accessible sand mines, and fed in water suspension through large mains to storage tanks from which it is delivered to the sump in such volume as may be required to maintain the sand density of the grading system. The pumps which deliver the sand mixture to the grading cones are operated at constant speed and are capable of throwing a

6-in. stream some 40 ft. above the top of the grader cone, which is itself approximately 50 ft. above the pump. The pumps are of the centrifugal type, using bronze rotors in separate cast-iron shells, which are housed in air-tight cast-iron casings. The grader cones are approximately 33 ft. high from the 6-in. receiving end to the bottom of the 8-ft. high by 12-ft. diameter top ring. Any overflow from the top of the grader is discarded, as the sand in the overflow is almost impalpable. Closer grading can be gained by recirculating each grade from the main cone through similar smaller cones, whereby each grade can be separated into a number of closer grades, and more of the fines eliminated from each grade.

The grinders are large steel discs faced with oak planking and special cast-iron runner bars so arranged that the sand-water mixture is thrown toward the outside of the disc as it spins. These discs are hung on a universal joint at the lower end of a vertical shaft which is driven by a 25-kw. synchronous motor. The whole assembly can be picked up by an overhead crane and moved from one position to another, or out of the line entirely, for refacing.

The G. & P. decks are driven by a variable speed a.c. motor through a rack and pinion drive, the rack being attached to the underside of the tables. Constant speed is obtained by a restraining brake at the end of the G. & P. line. The track upon which they move is the heaviest available railroad rail specially machined to a square head, and this track is level to an accuracy of less than plus or minus .001 in. over its entire length of nearly 1000 ft. Each deck car weighs approximately 3 tons, and the decks are machined true and then ground under the regular G. & P. grinding equipment.

Grinding sand varies from about .375 mm. grain size to about .037 mm. and the final grinding is accomplished with emory or alundum graded from .067 mm. to .027 mm. final grain size.

At the middle yard, the decks are examined and any broken glass removed and chipped glass cut out. Gaps so left are filled with plaster or if large, with set-out cullet. The plaster borders are rebuilt, and the line proceeds under the polishers.

Polishing

The polisher blocks consist of numerous cast-iron discs from 18 to 24 in. in diameter, faced with heavy felt pads. These blocks are distributed around the rim of a spider, with some toward the center. Each block is suspended freely on a ball-and-socket joint at the end of a pin which floats in a gland in the spider. The spider is suspended and driven similarly to the grinder head, except that there is no universal joint at the end of the drive shaft.

Polishing is accomplished by feeding rouge suspended in a copperas solution to the center of the polishing spider, whence it is delivered to the leading edge of each polisher block. The rouge tends to build up on the face of the felt and when this build-up has completely covered the felt and so long as it remains reasonably soft, polishing proceeds, with the generation of sufficient heat to volatilize the water; hence as the glass leaves the polishers the surface is completely dry and the glass at a temperature something more than 125° F. Rouge is red ferric oxide. It is screened through 300-mesh silk bolting cloth and mixed with copperas solution to a predetermined Baumé reading. It is mixed in large wooden vats and delivered to the polishers through a pipe system, propelled by all bronze centrifugal pumps. The lines are small in diameter and the velocity high to lessen the probability of settling and clogging.

To return to the sheet window-glass production, it was stated that up to the point of delivery of molten glass from the tank, the processes of plate glass and window glass were essentially identical.

Sheet Glass Production

In sheet glass manufacture, the glass is delivered to the working doghouse or drawing kiln, where a flat sheet is formed by drawing the glass vertically upward from the molten bath. In the Fourcault process, the glass is extruded through a slot in a clay shape called a debiteuse floating on the surface of the bath, which determines the width of the sheet and tends to hold the edges by chilling them. The glass is picked up by a bait which is lowered into the slot and then raised through a vertical conveyor to a height of some 30 ft. above the level of the tank, where the glass is cut into stock sheet sizes.

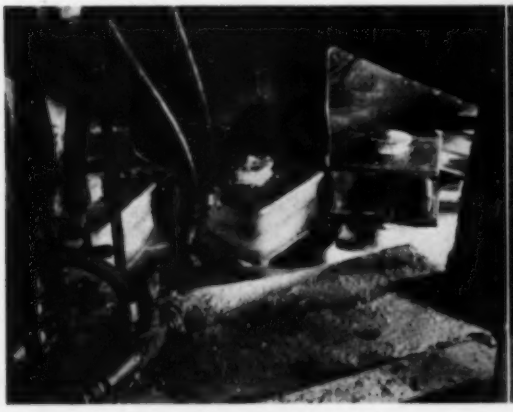
In the Colburn process, no debiteuse is used and the glass is drawn freely from the surface of this bath, with special edge-holding devices used to hold the width of the sheet and prevent its drawing down to a mere thread. A bait is used to start the ribbon which in this process is raised vertically only about 24 in.

The glass is still sufficiently soft to bend 90° over a large roller at the mouth of an horizontal roller lehr much like the plate-glass lehr. The pressure of the glass on the bending roll and the lehr rolls affords the traction to draw the glass continuously in a flat ribbon some 400 ft. long. At the lehr mouth, the glass is cut into stock sheets.

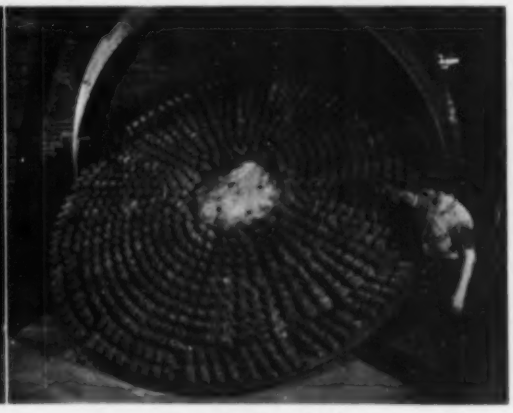
The Pennvernon process is more nearly similar to the Fourcault process than to the Coburn process and the authors believe it eliminates the inherent troubles to which the other two processes are subject.

The Pennvernon process eliminates the debiteuse of the Fourcault process and the bending roll of the Colburn process. The line of draw is determined with great accuracy by a completely submerged clay "drawbar" which acts to absorb or obscure just enough mass radiant heat to define sharply the line of draw directly over it and prevent wandering over the bath. Surfaces of the bath flow directly and smoothly into the surfaces of the sheet, which is freely drawn vertically upward some 6 or 7 ft. Thus the Pennvernon process prevents the sensitive hot glass surfaces from making contact with any extraneous equipment which might mar them until they have cooled and hardened sufficiently at the 7-ft. level so that the rolls of the vertical conveyor may clamp the ribbon sufficiently to afford traction without at the same time imprinting the surfaces.

The conveyor on both the Fourcault and Pennvernon machines consists of counter-balanced asbestos-covered rollers which are driven, and clamp the glass between them. This affords the traction to draw continuously the formed sheet away from the bath. At the top of the conveyor, which is also to some extent a lehr, vacuum-cup frames on overhead trolleys grasp the sheet as it rises above the cut-off point and travels upward with it until the cut is made, usually by mechanical means. The stock sheet thus formed is moved by hand to carriages, also suspended from trolleys, and moved to the examining and cutting room. Mechanical handling of sheet glass essentially ends at this point. The glass



Spray-coating the mortar edge.



A newly plated grinder head.

is cut into relatively small sizes and examined and graded in those sizes. It is moved manually to the packing room and packaged for shipment. Roller conveyors, electric industrial lift trucks and hand-lift trucks are used in moving the packed glass from the boxing room to storage or directly into cars. Packaging and package-handling in the case of plate glass is somewhat similar, except that plate-glass cases are not of standard sizes and are usually much larger and heavier than sheet-glass boxes, so overhead cranes also are used in loading plate glass into cars. Plate glass is never stored in boxes at the factory.

Laminated Safety Glass

Laminated safety glass is identified in one's mind with the glazing of automobiles, high speed streamlined trains and aeroplanes. The processes in this case are all of the assembly type and involve the handling of finished articles of commerce to be assembled into a single unit of a new product. The laminating medium used is sheet polyvinyl-acetbutyral supplied by several other manufacturers.

The vinyl sheet is received by rail or truck freight in large (not huge) rolls and handled manually to the storage and processing floor. As received, the sheet is coated with sodium bicarbonate to prevent its self-adhering, and this coating is not removed until just before lamination. The rolls of plastics are moved into a conditioning room where the sheet is festooned or draped in long loops over conveyor rolls much as in a wallpaper factory. The moisture content of the plastic is carefully stabilized at a desired minimum and then moved to the cutting room. Here the ribbon of plastic is cut into sheets of adequate size to cut the various contours required for the finished product. For many of the shapes, large cutting dies are available and piles of plastic are cut to contour by mechanical shears. Other shapes are cut to contour using glass or aluminum templates to guide a manually wielded sharp scalpel-like knife. Most of this work is performed by women. Piles of plastic are placed on dollies and moved manually to the assembly line.

Meanwhile, the glass from the factory is delivered to the glass-cutting room. As received, it is already cut to appropriate rectangular size to yield the desired finished contours. It is in piles of as many as 75 or 80 pieces, but these piles cannot be moved to a die-cutting machine. Each individual piece must be cut separately. Here also glass or aluminum templates are used as cutting guides. However, many contours adapt themselves to the design of semi-mechanical cutters. These consist of metal guide tracks which carry a cutting head. The operator places a rectangle of glass on the table under this cutting frame, grasps a knob handle on the cutting head and exerting a slight downward pressure, swishes the cutting head around the track. The cutter is so set that the axis of the cutting wheel is always at 90° to the line of the cut, and the plane of the cutting edge at 90° to the plane of the glass. This operation is much more rapid than hand-cutting to template. These machines could be and in some cases have been made wholly automatic. However, several things militate against their use, not the least of which is the cost of equipment for small quantities of a given contour.

Glasses are assembled in pairs onto small hand trucks and moved by hand to the assembly line. Here both glass and plastic pass through similar scrubbing equipment which thoroughly washes and dries the sheets. The plastic also passes through an antistatic device.

In a meticulously dust-free air-conditioned assembly line, the glass and plastic are assembled by hand into a sandwich. The assembly passes through an electric-heating chamber and between a series of rubber-covered rolls which squeeze the glass and plastic into intimate contact. All of this is accomplished on a continuous roller conveyor.

At the end of the conveyor, the glasses are piled on edge on large carriages which are moved by hand to the autoclave. They are lifted by an overhead hoist and set down into the autoclave which is approximately 50 in. in diameter by 120 in. high. The autoclave is filled with a fluid and the cover locked in place. The fluid continues to circulate through a heat exchanger and the temperature is built up to 260° F. Meanwhile the pressure has been built up to between 150 and 200 lb./sq.in., where it is held while the temperature drops to 160° F. The glasses remain in the autoclave for approximately 25 min., after which the lamination is complete and fully transparent safety glass has been made.

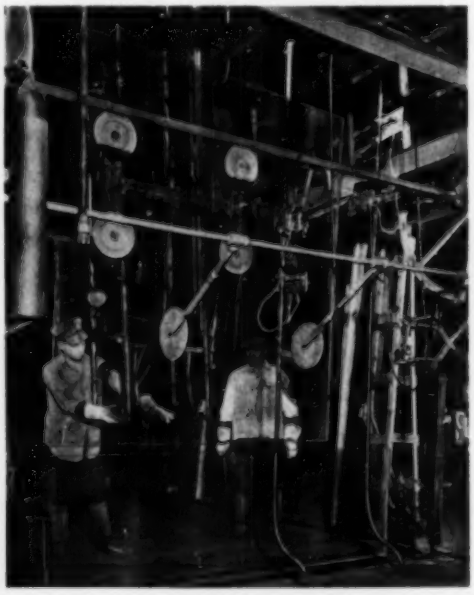
The glass is now moved to the edge-finishing department where most of the edging is accomplished by automatic edge-grinding machinery which carries the glass forward and rotates it so that each edge is finished as required, without any intermediate handling. Finished pieces are handled from floor to floor to the final examination room on an endless belt elevator equipped with long wooden pegs upon which the glass rests as it moves downward. At the foot of the elevator, it is removed by hand to an endless belt conveyor which runs past the examination stalls where girls lift each individual piece and examine it for extraneous inclusions. The approved glasses move on to the packing area at the end of the conveyor, are separately wrapped and packed into boxes by hand.

Other Flat Glass Products

In this day of superconsciousness of solar heating, air conditioning and insulation, double- or other multiple-glazed units have become a must in most residential construction, in refrigeration and in air conditioning. As a result two such competitive units have been developed which will remain clear and free from condensed moisture for a long indeterminate time, and afford the same insulation against heat gain or loss as is provided by an 8-in. brick wall, while at the same time affording perfectly clear vision of the distant scene. This paper will not go into the respective merits of these competitive products. Suffice it to say that they are competitive.

In these days a demand has arisen for heat-absorbing glass which will absorb considerable portions of the total radiant energy while transmitting almost any desired portion of visible light. But, one can't have both; hence, a compromise—high heat absorption connotes low light transmission and conversely, high light transmission connotes low heat absorption. Several heat-absorbing glasses of varying characteristics are generally available on the market.

On the other hand, while so often seeking to avoid direct solar radiation, often nonetheless people demand a source of energy which may or may not be utilized



Window glass cut-off.

as radiant energy. As a result of this demand, there has been developed an electric conducting glass which is called "Nesa" and which has found widespread use in defogging and deicing the windshields of military aircraft, and some application as a space-heating device, principally between a window and a desk or as a whole window installation. It affords the possibility of satisfactory electric panel heating.

It should be noted that heat-resistant glass is not generally available in flat glass form, though it has been developed to a high degree for ovenware, laboratory equipment and other special applications. Difficulties encountered in melting and refining this type of product make it almost impossible to produce heat-resisting glass of the clarity and freedom from internal defects such as ream or striæ characteristic of plate glass and flat-drawn sheet glass.

Fire-retardant glass has its only example in wire glass.

Glass Block

This brings up the subject of glass block which is being used so extensively in curtain walls construction in the United States today. This panel structure product is of recent origin and is a development of the middle thirties. Glass blocks, as the term is used, are hollow autogenously hermetically sealed units which are produced in three standard sizes—6 in., 8 in. and 12 in. square and 4 in. thick. The glass batch from which they are made contains ten different chemicals, each calculated to impart some specific property to the finished product. The raw batch comprises the same ingredients as those used in plate glass and window glass plus several others, each of which fulfills a specific purpose in making up a glass which is durable, free from bubbles and unmelted batch, clear in color, easy to melt and readily pressed into the desired shape.

As with other batch materials, the raw materials are carefully checked. Tramp iron is removed by passing the materials over a magnetic pulley before they enter the storage bins. They are weighed out from these bins in quantities which vary from 72.5% of the total batch to only .0005% and are then thoroughly mixed in a conventional-type mixer for some 3 min. The mixed batch which weighs approximately 1300 lb. is moved by dump truck and bucket belt elevator to storage bins above and adjacent to the melting tank, and is fed into the tank at a uniform rate by screw conveyor feeders.

The melted glass flows from the tank into 15-ft. long narrow troughs called "forehearths" in which the glass is conditioned to the final desired temperature. The glass flows like stiff molasses from the forehearth through a vertical 4-in. I.D. cylinder. A ceramic piston or plunger fitting loosely in this cylinder forces the glass through the cylinder in gobs which are cut off by metal scissors.

The free-falling gob of glass lands in a mold made of cast iron, stainless steel or bronze, carried on a 10-ft. diameter table that rotates in steps. Immediately after the gob falls into the mold of which there are 12 a machine, the table indexes to the next position where an air-driven plunger comes down upon the glass with sufficient pressure to force it to fill the space between the mold and the plunger. Thus a square dish is formed with a 2-in. high rim. This is half a block and at this stage, when removed from the press, the glass is rigid and at a temperature of about 1200° F. The inner surface of the molds and the face of the plunger bear the configurations which are pressed into the outside and inside surfaces of the glass block, respectively.

These half blocks are manually placed in pairs in a sealing machine where the edges are reheated to the softening point by means of a gas flame. The moist products of combustion are mechanically flushed by jets of dry air from the insides of the two halves just before they are brought together. This is done merely to lower the dew point of the entrapped air. When the two halves are forced together, the glass squeezes out slightly and forms a true glass seal. The average temperature of the glass block at the time of sealing is about 1100° F. so that when the entrapped air cools to room temperature a two-thirds vacuum develops in the block.

From the sealing machine the blocks are placed by hand on the endless chain belt of the lehr where they are annealed in about 4 hrs. time.

Final inspection is given to every single block and representative samples are removed from the production line and tested to destruction in various ways.

In order that the blocks may be laid up in cement mortar to form a strong watertight wall, the four edges, generally called the mortar edges, are spray-coated with a material that will provide the proper resilient medium between the glass and mortar.

Cardboard shipping cartons take twelve 6-in., eight 8-in. or three 12-in. blocks. These blocks find their way into the walls of practically every type of building from chemical plant to residence. They are structurally strong even though they are not intended to carry superimposed loads. They have about the same insulating value as 8 in. of ordinary brick, and will transmit a high percentage of the incident light. In fact the light-directing type of block has prisms molded into the inside surfaces that serve to direct the incident light to the ceiling and the back of the room, thus making them ideally suited for classroom fenestration and other places where good-seeing conditions are important. In certain chemical plants where acid fumes are present, acid-resisting cement is used in the mortar or the regular mortar joints are painted with an acid-resisting coating.

Foamglas

Another unique all-glass product of recent origin is cellular glass or Foamglas as it is called by the only company that manufactures it in this country. Foamglas is a rigid block type of insulation composed entirely of glass and a minute quantity of carbon. It is cellular in structure and the cells are not intercommunicating. This latter feature, of course, plus the fact that it is made entirely of glass gives it its high resistance to the passage of moisture. In fact it was this property plus its light weight of 10 lb./cu.ft. that prompted the Navy in 1942 to become interested in substantial quantities for flotation purposes.

With this incentive the first factory was built in 1942 in this country even though development work started in France in the early thirties and in this country a few years later.

As is the case in practically all glass products, the raw materials that go to make up Foamglas are selected for this particular purpose; it is necessary to include materials that will generate gases under specific circumstances.

The first step in the process as now practised is to produce a glass melt in much the same manner as described above under Glass Block. But in the case of Foamglas manufacture the molten glass is drawn out of the tank as a continuous thin film, allowed to cool rapidly, and then crushed in a rapidly revolving ring crusher from which it is elevated to a large storage bin. From the storage bin the glass is weighed out and fed, along with a fraction of one per cent of carbon black the gassing agent or "yeast," into large pebble mills where the glass is further crushed, pulverized and intimately mixed with the carbon black. The resulting dry powder weighs about 50 lb./cu.ft.; therefore, its volume before cellulation is only one-fifth that after cellulation.

The powder is automatically weighed in a specially designed rectangular vibrating and dumping device that places the batch quite uniformly over the bottom of the two-part mold pan to a depth of about 1 in. The mold pans are simple rectangular slightly tapered welded units made of ⅛-in. thick stainless steel. The top half is the same as the bottom half and is merely inverted and set in place over the bottom half thus forming a box ½ filled with the powder. To prevent the powder from sticking to the mold pans when heated, the pans are spray-coated each trip with a clay parting agent.

The partially filled mold pans, 13 in. × 19 in. × 5 in. high, are conveyed through a 60-ft. long, 5 ft. wide direct gas-fired roller hearth furnace, in which the temperatures range roughly from 1400° F. at the entrance to 1700° F. near the middle and 1300° F. at the exit. During its travel through this temperature cycle in about an hour's time, the glass powder first sinters, gets hard and shrinks like mud in the sun. Then as its temperature rises it softens and begins to swell as gases are generated within the viscous mass. The expansion of the gases in the tiny individual cells causes the glass to fill the mold and slightly raise the top half.

As the filled mold comes out of the furnace the cover is removed and the 1300° F. cellular glass block is quickly lifted from the bottom pan and placed on end in a 10-ft. wide, 130-ft. long direct-fired annealing lehr. Since this product is a good insulating material, it takes an unusually long time to anneal and bring down to room temperature. In the case of a 5-in. thick block the total time in the lehr is of the order of 12 hrs.

The Foamglas block as it comes from the lehr is somewhat irregular and slightly oversize and must therefore be trimmed to size. This is done quite readily and with precision in semiautomatic equipment using fairly open-grained carborundum wheels. And if it is desired to cut a standard 4-in. × 12-in. × 18-in. block into two 2-in. thick blocks this is done with a specially chrome-plated band saw. The finished blocks are packed in cardboard cartons.

During the past several years a portion of the rectangular blocks has been further cut and fabricated in the factory into curved shapes for use on various types of chemical processing equipment and pipe covering. The bulk of this work is done with abrasive wheels and band saws.

Because of its resistance to moisture vapor penetration, Foamglas is the ideal insulating material for cold storage work especially where its rigidity and strength add to the structural integrity of the installation. Of course the joints between the blocks must be sealed to obtain a completely vapor-tight structure. This is readily done with hot asphalt or some suitable mastic or adhesive suited to the conditions of the particular job. This material is being used extensively as insulation under floors, in walls and on roofs of all types of structures. Recently it has been used as the core material in prefabricated concrete panels 6 in. thick and as large as 16 ft. square.

Recapitulation

Each of these separate products has or may have a direct relation to chemical engineering practice in one way or another. Plate glass and sheet window glass have long been used in chemical laboratory hoods and other equipment. Tempered glass, which is an especially heat-treated plate glass, due to its several times greater strength than the annealed product, may be used in many places where plate glass or window glass would have inadequate strength to afford protection. It has been used as the observation windows in wind tunnels and similar equipment. Under the repercussion of explosions it is quite the most resistant of any of the transparent materials. Laminated safety glass affords excellent protection against scattering of glass fragments and may be assembled in sufficient thickness to give effective protection against the penetration of 50 caliber armor-piercing bullets fired from a distance of 50 ft. Even heavier bullet-resistant glass has been built.

Glass block offers many unique advantages in the erection of air-conditioned or insulated structures, with full availability of natural light values, while Foamglas presents an entirely incorrodable vermin-proof, vapor-tight thermal insulation which is essentially indestructible.

The chemical and physical control of glass components and collateral finishing materials is exacting. All materials are analyzed chemically for purity and uniformity of composition within close limits. Grain size of melting sand, lime or limestone and soda ash are carefully controlled. Rouge for polishing must have exact characteristics which may not vary beyond an established apparent density on a 1-in. cubic measure. And since nearly all the chemical elements enter in one way or another into many glass products, they are purchased to exacting specifications which are carefully checked. Even the cars in which materials are shipped must frequently be checked for freedom from extraneous contaminating materials. Heat exchangers are utilized to maintain the temperature of forming rolls at something below 700° F., even though in contact with molten glass at 2100° F., as well as in the control of autoclave temperatures as previously noted.

Strength of Materials

It is likely that certain chemical engineers are interested in the strength of materials. This paper does not give an exhaustive discussion of the subject; and more complete data may be derived from published sales literature. However, glass is a moody material and resents having its innards any more exposed to general view than may be unavoidable. It seems to feel that it is already sufficiently transparent to satisfy even the most critical scrutiny. It may therefore be truly said that no one really knows what the tensile strength of glass is. It varies from some 300,000 lb./sq.in. on a tiny fiber one or two thousandths of an inch in diameter to a questionable minimum value on a thin flat plate of some 3,000 lb./sq.in.; and if one were to draw that 300,000 lb./sq.in. fiber between his fingers and test it again, the strength would have fallen to something of the order of 25,000 lb./sq.in. In the testing of flat glass plates under modulus of rupture procedures, the mean average value proves to be about 6,500 lb./sq.in. of cross section, with a maximum of approximately 12,000 lb./sq.in. and a minimum of 3,000 lb./sq.in. depending upon the rate of loading. Small, invisible surface flaws have an inordinate effect upon strength determinations.

It seems to be well established that any square panel of annealed glass 1 in. thick will support a total evenly distributed load of 21,000 lb. and a safe factor for loading seems to be dependent upon the square of the thickness of the plate. This seems to be reasonably accurate for thicknesses up to 1¼ in., but less so for greater thicknesses.

Tempering the glass by sudden quenching increases its strength manyfold. Glass always breaks under a tensile stress and the great increase in strength derived from tempering results from the fact that the outermost surfaces have been put under relatively high compression while the neutral plane of the sheet has been placed under a correspondingly high tension. The net result is an increase in the mean average modulus of rupture to some 29,500 lb./sq.in. and of the minimum modulus to something approaching 24,000 lb./sq.in. When this tempered glass breaks, it crumbles into rock candy like fragments. These fragments approach cubes of the dimensions determined by the thickness of the glass. They more or less interlock and if securely held in a frame, tend to bind themselves in more tightly—if not held in a frame, the fragments tend to fly in the plane of the glass, never at an angle to that plane.

Laminated safety glass is slightly weaker than homogeneous annealed glass of the same over-all thickness simply because the sum of the strengths of the component glasses is less than the unit strength of the homogeneous piece. However, the resistance of the laminated glass to penetration by impact is materially greater than the impact resistance of annealed glass of the same over-all thickness. This is due to presence of the plastic to interrupt the progress of the conical fracture of the glass from one plate to the next, thereby increasing the surface of impact and more widely distributing the load.

Glass blocks are primarily intended for use in curtain walls or other non-load bearing applications. Because of the low conductivity of glass and the insulation value of the air space, they do to some degree afford a fire-resistant dividing wall. Underwriters' Laboratories, Inc. in their fire tests give glass-block panel a Class *F* rating.

Foamglas is primarily an insulating material particularly adapted to low temperature applications between —350° F. and +800° F. The manufacturer's literature and specifications give the necessary installation details for all the various applications. It will readily sustain a well-distributed load of 20 lb./sq.in., but it may readily be cut to shape or size with an ordinary saw or a pocket knife without hazard of propagation of cracks beyond the point or line of contact. Its density is approximately 9 lb./cu.ft. with a specific gravity approaching .15 or less.

Finally, glass in one form or another constitutes one if not the prime prerequisite of modern education, development, research, and culture. Without it there would be no Mount Palomar telescope, no microscope, telescope, nor electron microscope. Spectacles upon which many will ultimately come to depend for any degree of vision would be an unknown commodity. Spectroscopy, bacteriology, synthesis, incandescent electric lights—and many more would still be the stuff of which dreams are made if it were not for glass and its many varied attributes.

As the *Glass Manual* states glass is the "incomparable servant of man and all his possessions. Its future, and the future of man because of it, is beyond the power of imagination."

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TRUE TEMPERATURE DIFFERENCE IN SPLIT FLOW

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Use of split flow is a fairly common practice for the attainment of low-pressure drops in commercial heat-transfer equipment. The geometry of a hot and cold stream in split flow provides a temperature difference arrangement which is neither counterflow nor parallel-counterflow as embodied in the common 1-2 exchanger of industry. The equation is derived here for the true temperature difference in split-flow exchangers together with methods for its use. It is also shown that the equation of Underwood which was derived for a 1-2 parallel-counterflow exchanger is a special case of the more general split-flow equation.

When the ratio of the true temperature difference for 1-2 parallel-counterflow to the logarithmic mean for counterflow is greater than 0.90 the true temperature difference in 1-2 parallel-counterflow and in split flow deviate by less than 10 per cent. Since the split-flow equation requires a rather lengthy trial-and-error solution this generalization permits a rapid calculation of the true temperature difference under the conditions noted.

THE most favorable utilization of the temperatures of two fluid streams for the promotion of heat transfer occurs when the streams are arranged in counterflow where the logarithmic mean temperature difference applies. For reasons either of mechanical construction, to induce fluid turbulence or to prevent an excessive fluid pressure drop, commercial heat-transfer apparatus often must be designed employing heat and fluid flow patterns which deviate from counterflow. Bowman, Mueller and Nagle (*1*) published a comprehensive summary of the temperature difference equations applying to numerous commercial heat flow patterns. They reduced the various equations to a convenient and useful form involving the logarithmic mean temperature difference for counterflow and a temperature difference factor F_T which is a function of the parameters $R = (T_1 - T_2)/(t_2 - t_1)$ and $S = (t_2 - t_1)/(T_1 - t_1)$ where T_1 and T_2 are the inlet and outlet hot fluid temperatures and t_1 and t_2 the inlet and outlet cold fluid temperatures. The factor F_T is defined for noncounterflow patterns as the ratio of the true temperature difference for a noncounterflow pattern to the logarithmic mean which would be obtained if the hot and cold fluids were considered to be in counterflow.

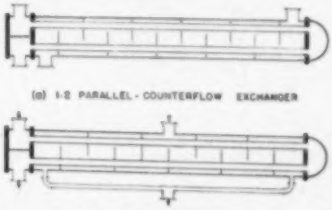
Typical noncounterflow patterns are encountered in heat exchangers having one shell pass and two or more tube passes as in (a) of Figure 1 in which some of the tube passes are in parallel flow and some in counterflow with the shell pass, and in the various orientations of crossflow exchangers. Solutions for the true temperature difference of a number of the cases for crossflow have not appeared in the literature so far although equations have appeared covering the common patterns of parallel counterflow.

A problem often arises in the design of equipment for gases at low and moderate pressures or for unequal hot and cold liquid streams whose mean temperatures differ greatly and whose film coefficients are both high. It is often difficult under such conditions to accomplish heat transfer in heat-exchanger shells within the limitations of a reasonable static pressure drop. One of the possibilities of accomplishing heat transfer with less pressure drop than is encountered in the shells of conventional parallel-counterflow exchangers is shown by the split flow exchanger (b) of Figure 1. The pressure drop through the shell of an exchanger may be considered approximately in direct proportion to the length of path and in proportion to the square of the mass velocity of shell-side fluid flow, that is when entrance, exit, direction pressure losses and changes in hydraulic radius are neglected. It may be assumed in split flow (b) that the halves of the fluid travel one half the tube length in a conduit whose flow area is identical with that of the parallel-counterflow exchanger of Figure 1 (a). The resultant pressure drop in (b) is therefore approximately only ⅛ that of (a). A study of the true temperature difference for this relatively important case has not appeared in the literature heretofore.

Consider the split-flow exchanger as represented diagrammatically in Figure 2. It may be considered to be the sum of two separate heat exchangers A and B having equal surfaces. By virtue of shell-side baffles the shell fluid may be considered mixed at any cross section at right angles to the longitudinal axes of the tubes. The inlet and outlet temperatures of the hot fluid, flowing through the shell are T_1 and T_4 and of the cold fluid flowing through the tubes, t_1 and t_2 respectively. B in Figure 2 may be considered identical with a 1-2 parallel-counterflow exchanger although A is not. The following assumptions apply:

1. Equal weight flow of shell fluid in A and B
2. Constant specific heats for both fluids in both A and B
3. Equal surface in all passes and in A and B
4. Constant and equal over-all coefficients of heat transfer in A and B
5. Shell fluid completely mixed at any cross section
6. No partial phase changes
7. No heat losses

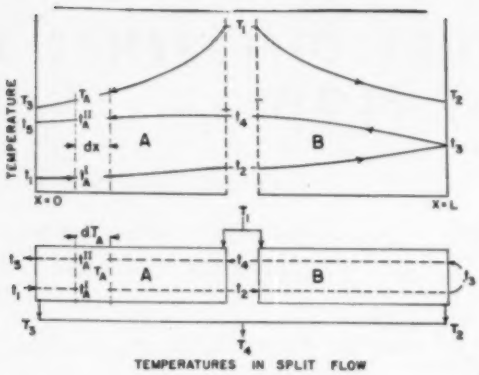
Let W and w represent the weight flows respectively of the hot and cold fluids in the shell and tubes respectively, C and c their specific heats and let L be the tube length. For the temperature notation reference should be made to Figure 2. Writing the heat balance



(a) 1-2 PARALLEL-COUNTERFLOW EXCHANGER

(b) SPLIT FLOW EXCHANGER

Fig. 1.



TEMPERATURES IN SPLIT FLOW

Fig. 2.

around section A of the split-flow exchanger

$$\frac{WC}{2}(T_1 - T_3) = wc(t_2 - t_1 + t_5 - t_4) \quad (1)$$

Consider any cross section such as $0 - 0'$ in A and writing the heat balance around the right end of A

$$\frac{WC}{2}(T_1 - T_A) = wc(t_2 - t_A{}^I + t_A{}^{II} - t_4) \quad (2)$$

Differentiating Equation (2) for the increment of length dx of A between $0 - 0'$ and $1 - 1'$

$$\frac{WC}{2}dT_A = wc(dt_A{}^I - dt_A{}^{II}) \quad (3)$$

For heat transfer across the first pass only of A between $0 - 0'$ and $1 - 1'$

$$wcdt_A{}^I = Ua''dx(T_A - t_A{}^I) \quad (4)$$

where U is the over-all coefficient of heat transfer and a'' is the square foot of external tube surface per foot of tube length. For the second pass only

$$-wcdt_A{}^{II} = Ua''dx(T_A - t_A{}^{II}) \quad (5)$$

Substituting Equations (4) and (5) in Equation (3)

$$\frac{WC}{Ua''}\frac{dT_A}{dx} = 4T_A - 2(t_A{}^I + t_A{}^{II}) \quad (6)$$

Differentiating Equation (6) with respect to x, substituting Equations (4) and (5) in the result, and eliminating $(t_A{}^{II} - t_A{}^I)$ and $(t_4 - t_2)$ one obtains

$$\frac{d^2T_A}{dx^2} - \frac{4Ua''}{WC}\frac{dT_A}{dx} + \left(\frac{Ua''}{wc}\right)^2\left[T_3 + 2\frac{wc}{WC}(t_5 - t_1) - T_A\right] = 0 \quad (7)$$

Let $z_A = T_3 + 2\frac{wc}{WC}(t_5 - t_1) - T_A$ (8)

Then $\frac{dz_A}{dx} = -\frac{dT_A}{dx}$ and $\frac{d^2z_A}{dx^2} = -\frac{d^2T_A}{dx^2}$

Substituting in Equation (7)

$$\frac{d^2z_A}{dx^2} - \frac{4Ua''}{WC}\cdot\frac{dz_A}{dx} - \left(\frac{Ua''}{wc}\right)^2 Z_A = 0 \quad (9)$$

Equation (9) is a linear differential equation with constant coefficients and may be rewritten in terms of an operator. Then

$$m^2 - \frac{4Ua''}{WC}m - \left(\frac{Ua''}{wc}\right)^2 = 0$$

and

$$m = \frac{Ua''}{WC}\left[2 \pm \sqrt{4 + \left(\frac{WC}{wc}\right)^2}\right]$$

Let

$$\lambda = \sqrt{4 + \left(\frac{WC}{wc}\right)^2}$$

then

$$m = \frac{Ua''}{WC}(2 \pm \lambda)$$

The solution of Equation (9) is then

$$Z_A = g_1e^{m_1x} + g_2e^{m_2x} \quad (10)$$

where

$$m_1 = \frac{Ua''}{WC}(2 + \lambda)$$

and

$$m_2 = \frac{Ua''}{WC}(2 - \lambda)$$

g_1 and g_2 are constants of integration. Evaluated when

$$x = 0 \text{ and } T_A = T_3$$

and when

$$x = \frac{L}{2} \text{ and } T_A = T_1$$

these become

$$g_1 = \frac{(T_3 - T_1) + 2\frac{wc}{WC}(t_5 - t_1)\left[1 - e^{m_2L/2}\right]}{e^{m_1L/2} - e^{m_2L/2}} \quad (11)$$

$$g_2 = \frac{(T_3 - T_1) + 2\frac{wc}{WC}(t_5 - t_1)\left[1 - e^{m_1L/2}\right]}{e^{m_2L/2} - e^{m_1L/2}} \quad (12)$$

Determination of Mean Temperature Difference. Differentiating Equation (10), eliminating dz_A/dx and dT_A/dx to permit use of thermal temperatures alone and substituting values for m_1, m_2, g_1 and g_2 above gives

$$(m_1 - m_2)L = 2\ln_e \frac{\lambda\left[T_3 - T_1 + 2\frac{wc}{WC}(t_5 - t_1)\right] - e^{m_1L/2} - \frac{wc}{WC}(t_5 - t_1)(\lambda + 2) + t_1 + t_5 - 2T_3}{\frac{wc}{WC}(t_5 - t_1)(\lambda - 2) + t_1 + t_5 - 2T_3} \quad (13)$$

The total heat transferred in the section A of the exchanger is also defined by

$$WC(T_1 - T_3)/2 = Ua''L\Delta t_A \quad (14)$$

where Δt_A is the mean temperature difference in section A. From the values of m_1 and m_2

$$(m_1 - m_2)L = 2Ua''\lambda L/WC \quad (15)$$

Eliminating $2Ua''L/WC$ between Equations (14) and (15)

$$(m_1 - m_2)L = \lambda(T_1 - T_3)/\Delta t_A \quad (16)$$

Eliminating $(m_1 - m_2)L$ between Equations (13) and (16) gives

$$\Delta t_A = \frac{\lambda(T_1 - T_3)/2}{\ln_e \frac{\lambda\left[T_3 - T_1 + 2\frac{wc}{WC}(t_5 - t_1)\right]e^{-m_2L/2} - \frac{wc}{WC}(t_5 - t_1)(\lambda + 2) + t_1 + t_5 - 2T_3}{\frac{wc}{WC}(t_5 - t_1)(\lambda - 2) + t_1 + t_5 - 2T_3}} \quad (17)$$

In Equation (17) it is still necessary to evaluate $m_2 \frac{L}{2}$. Eliminating $\frac{Ud''L}{WC}$ between m_2 and Equation (14)

$$-m_2 L/2 = (T_1 - T_3)(\lambda/2 - 1)/2\Delta t_A \tag{18}$$

Equation (17) is perfectly general and by solving Equation (1) for $T_3 - T_1$ and setting $t_2 = t_4$, it reduces to Underwood's (2) solution for the 1-2 parallel-counterflow exchanger. Thus, Underwood's solution is but a special case of a more general expression as defined by Equation (17). A heat balance around both A and B results in

$$wc/WC = (T_1 - T_4)/(t_5 - t_1) = R \tag{19}$$

Eliminating wc/WC in λ and in Equation (19)

$$\lambda = \frac{\sqrt{4R^2 + 1}}{R}$$

Since the shell fluid mass rate is the same in section A and section B

$$T_2 + T_3 = 2T_4 \tag{20}$$

The heat load in section A, Q_A, is given by the fundamental equation of heat transfer where A is the total surface in the exchanger.

$$Q_A = UA\Delta t_A/2 = WC(T_1 - T_3)/2 \tag{21}$$

And the heat load in section B, Q_B, is given by

$$Q_B = UA\Delta t_B/2 = WC(T_1 - T_2)/2 \tag{22}$$

Since A and B contain equal surface and the coefficient of heat transfer is considered constant and identical in both, elimination of $UA/2$ between Equations (21) and (22) results in

$$Q_B/Q_A = \Delta t_B/\Delta t_A = n = (T_1 - T_2)/(T_1 - T_3) \tag{23}$$

n expresses the ratio of heat load and mean temperature difference between section B and section A which are naturally in direct proportion. Eliminating T_2 between Equations (20) and (23) and solving for T_3

$$T_3 = [2T_4 + (n-1)T_1]/(n+1) \tag{24}$$

and

$$T_1 - T_3 = 2(T_1 - T_4)/(n+1) \tag{25}$$

The weighted mean temperature difference, Δt, for the entire exchanger is defined by

$$\Delta t = \frac{Q_A + Q_B}{Q_A/\Delta t_A + Q_B/\Delta t_B} \tag{26}$$

Simplifying Equation (26) through use of Equations (21), (22) and (23)

$$\Delta t = \Delta t_A (n+1)/2 \tag{27}$$

Substituting Equations (18), (19), (24), (25) and (27) in Equation (17) and employing only terminal temperatures one obtains

$$\Delta t = \frac{\lambda(T_1 - T_4)/2}{ln_e \dfrac{\frac{2\lambda n(T_1 - T_4)}{n+1} e^{\frac{T_1 - T_4}{2\Delta t}\left(\frac{\lambda}{2} - 1\right)} - (T_1 - T_4)(\lambda + 2) + t_1 + t_5 - \frac{4T_4 + 2(n-1)T_1}{n+1}}{(T_1 - T_4)(\lambda - 2) + t_1 + t_5 - [4T_4 + 2(n-1)T_1]/(n+1)}} \tag{28}$$

Use of Equations. While Equation (28) is the over-all equation for the exchanger it is not of direct use since it contains two unknowns, Δt and n. If a value of n is assumed then Δt may be calculated and Δt_A is obtained from Δt by

$$\Delta t_A = 2\Delta t/(n+1) \tag{29}$$

and

$$Q_A = Q/(n+1)$$

From Underwood's equation Δt_B is given by the usual equation for 1-2 parallel-counterflow

$$\Delta t_B = \frac{\sqrt{(T_1 - T_2)^2 + (t_4 - t_2)^2}}{ln_e \dfrac{T_1 + T_2 - t_2 - t_4 + \sqrt{(T_1 - T_2)^2 + (t_4 - t_2)^2}}{T_1 + T_2 - t_2 - t_4 - \sqrt{(T_1 - T_2)^2 + (t_4 - t_2)^2}}}$$

in which t_4 and t_2 are unknown as well as Δt_B. Furthermore two possibilities exist concerning t_4 since it lies directly under the hot shell inlet. It may be greater or less than t_5 depending upon the closeness of the approach or cross of T_4 and t_5. In order that t_4 and t_2 may be obtained for the solution of Δt_B it is first necessary to calculate the heat transferred in each pass of A which in turn is dependent upon the respective temperatures T_A, $t_A{}^I$ and $t_A{}^{II}$. These may be obtained with the aid of Equations (14) and (17) by replacing T_1 by T_A. Then assume an incremental change dT_A in T_A and obtain Δt_A. For a small increment the true temperature difference on each pass may be assumed to be identical with the logarithmic mean between the terminal temperature differences of the shell temperatures and the individual passes. By assuming the final value of T_A for the increment the final values of $t_A{}^I$ and $t_A{}^{II}$ may be obtained by trial and error such that the heat balances and the weighted temperature differences in A check. By continuing the procedure from $x = 0$ to $x = L/2$ values of t_4 and t_2 can be obtained.

This refinement is rarely necessary, however, because t_4 and t_2 can be approximated by an extension of the method described here to the entire exchanger, A. By assuming that the logarithmic mean temperature difference for each pass of A as determined for the terminal temperatures of A is identical with the true temperature difference for that pass, then if t_5 is greater than t_4

$$t_2 = t_1 + fQ/wc(n+1)$$
$$t_4 = t_5 - (1-f)Q/wc(n+1)$$

where f is the fraction of Q_A transferred in the lower tube pass of A. The balance on A for the individual temperature differences is

$$Q_A/\Delta t_A = fQ_A/\Delta t_{AI} + (1-f)Q_A/\Delta t_{AII}$$

In terms of the assumed value of n

$$\Delta t_{AI} = \frac{T_1 - T_3 - fQ/wc(n+1)}{ln_e[T_1 - t_1 - fQ/wc(n+1)]/(T_3 - t_1)}$$

and

$$\Delta t_{AII} = \frac{T_1 - T_3 + (1-f)Q/wc(n+1)}{ln_e[T_1 - t_5 + (1-f)Q/wc(n+1)]/(T_3 - t_5)}$$

The error introduced by the use of approximated values is small since there is less heat transferred in the upper pass having the closer approach to the shell outlet temperature. If t_4 is greater than t_5 heat must be recovered from the cold fluid while it travels through the hot pass. Let F be the heat removed from the hot pass for which

$$t_2 = t_1 + Q/wc(n+1) + F/wc$$
$$t_4 = t_5 + F/wc$$

The heat balance on A for the individual temperature differences is

$$\frac{Q_A}{\Delta t_A} = \frac{Q/(n+1) + F}{\Delta t_{AI}} - \frac{F}{\Delta t_{AII}} \qquad (30)$$

and

$$\Delta t_{AI} = \frac{T_1 - T_2 - Q/wc(n+1) - F/wc}{ln_e[T_1 - t_1 - Q/wc(n+1) - F/wc]/(T_2 - t_1)}$$

and

$$\Delta t_{AII} = \frac{T_1 - T_3 - F/wc}{ln_e[T_1 - t_5 - F/wc]/(T_3 - t_5)}$$

Having calculated f or F by trial and error, t_2 and t_4 may also be computed and from them the value of Δt_B is obtained by Underwood's equation. Applying the over-all balance

$$Q/\Delta t = Q_A/\Delta t_A + Q_B/\Delta t_B \qquad (31)$$

If Equation (31) checks, the proper value of n has been assumed and Δt is the value which was calculated from Equation (28) for the assumed value of n.

Numerical Solution. 4000 lb./hr. of a hot fluid (specific heat = 0.5) at 250° F. are cooled to 150° F. in the shell of a split-flow exchanger by 5000 lb./hr. of a cold fluid (specific heat = 1.0) which is heated from 100 to 140° F. The question is what is the true temperature difference for split flow.

1. Assume
$n = 0.9$, $\Delta t = 59.0°$ F. from Eq. (28)
$Q_A = 105,200$ B.t.u./hr.,
$Q_B = 94,800$ B.t.u./hr.
2. $\Delta t_A = 62.2°$ F. from Eq. (29)
3. $F = 38,000$ B.t.u./hr. from Eq. (30)
4. $t_2 = 128.6°$ F., $t_4 = 147.6°$ F.
$T_3 = 155.2°$ F. from Eq. (23)
5. $\Delta t_B = 51.2°$ F. from Underwood's equation
6. From Eq. (31), $\Delta t = 59.0°$ F., checks closely the value obtained from Δt_A and Δt_B substantiating the assumed value of $n = 0.9$

Conclusion. The logarithmic mean temperature difference for counterflow is 76.2° F. For a 1-2 exchanger the temperature difference factor F_T is 0.86 and the temperature difference is 65.5° F. compared with 59.0° for split flow. For most practical problems when F_T for a 1-2 exchanger is greater than 0.9 the influence of the hot shell inlet temperature occurring at the middle of the tubes is not severe and some time may be gained at the expense of accuracy by calculating split flow as 1-2 parallel-counterflow.

Notation

A = total surface in exchanger, sq.ft.
a'' = external surface per linear unit of tube, ft.
C = specific heat of hot fluid, B.t.u./(lb.)(° F.)
c = specific heat of cold fluid, B.t.u./(lb.)(° F.)
F = heat removed from hot pass of cold fluid in A, B.t.u./hr.
F_T = temperature difference factor, dimensionless
f = fraction of heat transferred from cold pass in A
g_1, g_2 = integration constants
L = tube length, ft.
m_1, m_2 = integration constants
n = ratio of Q_B/Q_A, dimensionless
Q = heat transferred, B.t.u./hr.
Q_A, Q_B = heat transferred in A and B, B.t.u./hr.
R = ratio wc/WC, dimensionless
T_A = hot fluid temperature in A, °F.
$t_A{}^I$ = cold fluid temperature in cold pass of A, ° F.
$t_A{}^{II}$ = cold fluid temperature in hot pass of A, ° F.
T_1 = hot fluid inlet temperature, ° F.
T_2 = hot fluid outlet temperature from B, ° F.
T_3 = hot fluid outlet temperature from A, ° F.
T_4 = combined hot fluid outlet temperature, ° F.
t_1 = cold fluid inlet temperature, ° F.
t_2 = cold fluid temperature at outlet of cold pass in A, ° F.
t_3 = cold fluid temperature at end of B, ° F.
t_4 = cold fluid temperature at inlet of hot pass in A, ° F.
t_5 = cold fluid outlet temperature, ° F.
Δt = true temperature difference for split flow, ° F.
Δt_A = mean temperature difference, ° F.
Δt_{AI}
Δt_{AII} = logarithmic mean temperature difference for first pass and second pass of A respectively, ° F.
Δt_B = true temperature difference for 1-2 parallel-counterflow exchanger, ° F.
U = over-all coefficient of heat transfer, B.t.u./(hr.)(sq.ft.)(° F.)
W = weight flow of hot fluid, lb./hr.
w = weight flow of cold fluid, lb./hr.
x = distance along tube, ft.
z_A = equation defined by (8)
λ = equation defined after equation (19)

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Discussion

K. A. Gardner (Griscom-Russell Co.): I think that some of the fright resulting at the sight of this equation can be removed by putting it in terms of the same dimensionless temperature ratios that Underwood and Nagle used originally and making simple corrections above which the logarithmic *MTD* is multiplied, which is the common procedure for other than counterflow heat exchanges. There would be considerable work involved for the fellow who does it, but once it is done, there it is and a cinch to use.

D. Q. Kern: Of the limited number of preprints available, about some 50 people wrote in. Of that number, I would say, a good fraction wrote in and asked why it hadn't been put in terms of R and S or R and K parameters. The answer is simply that having tested it, I never had the time in which to do it myself. However, if you would like to, I would have no objection to your picking it up at that point and setting it within those parameters. You see, you have to have three parameters no matter how you work it, I'm quite certain, and that will not lead you to the same type of graph.

Anonymous: Why?

D. Q. Kern: Because you still have one additional condition that has to be solved on the intermediate temperature and at least in probing for it it doesn't drop out readily.

K. A. Gardner: You have one inlet temperature and one mixed outlet temperature on the shell fluid and you have one inlet temperature and one outlet temperature on the tube fluid, and by taking I think R, which is

$$\frac{T_1 - T_2}{t_2 - t_1}$$

and P which is

$$\frac{t_2 - t_1}{T_1 - t_1}$$

they are the common parameters—I think it can be done in that way. The other one has to drop out somehow. I don't say that it will be easy to make it but I think it will turn out that way.

(Presented at Boston Meeting, Swampscott, Mass.)

KANSAS CITY MEETING

TECHNICAL PROGRAM

WILLIAM W. NIVEN, JR.

Midwest Research Institute, Kansas City, Missouri

THE Midwest meeting will get under way in Kansas City Sunday, May 13, with registration and an informal complimentary buffet snack for registrants and their wives, entitled "Kansas City Greets You." Be sure to come in time to meet old friends and make new ones at this occasion.

The programs for Monday through Wednesday will include four technical and two nontechnical symposiums, two sessions of general subjects, and one evening devoted to "bull sessions" on five different topics. Abstracts of the papers will be furnished in advance to Institute members.

Program and Sessions

Symposium: Reaction Kinetics

This symposium will be presented Monday morning, May 14, with Bernard W. Gamson of the Great Lakes Carbon Corp. presiding. The kinetics of physical mass transfer, as applied to gases in single-phase laminar flow through granular beds, will be discussed by Merk Hobson and George Thodos of Northwestern University. Richard Bartholomew and Donald Katz of the University of Michigan will report on studies of heat-transfer coefficients to fixed fluidized beds, wherein the bed materials consisted of sand, aluminum, and calcium carbonate particles fluidized by air. A study of the steady-state heat transfer between solid and gas in fixed and fluidized beds will be reported by Jacob Eichhorn and Robert R. White of the University of Michigan, as a function of particle size, gas velocity, and gas properties. The design problem of predicting conversion as a function of catalyst bed depth in fixed-bed reactors is to be discussed by R. W. Schuler, V. B. Stallings, and J. M. Smith of Purdue University.

J. F. Maurer and C. M. Sliepcevich of the University of Michigan will report on a study of the effect of pressure on the catalytic dehydration of butanol-1. A study of fundamental kinetics of individual early-stage phenol-formaldehyde condensation reactions will be reported by F. C. Stults, R. W. Moulton, and Joseph McCarthy of the University of Washington, and a discussion will be presented of the applicability of these data to continuous-flow tubular condensation reactors. Finally, the rate of high-pressure catalytic formation of methane from carbon monoxide and hydrogen will be discussed by John A. Pursley, Robert R. White, and Cedomir Sliepcevich of the University of Michigan.

Walter W. Deschner, chairman of Program Committee.

Symposium: Safety in Chemical Plant Operations

The safety symposium, with Matthew M. Braidech of the National Board of Fire Underwriters presiding, will run concurrently on Monday morning with the Reaction Kinetics Symposium. Discussions relative to the rolls of management, the safety engineering, and the chemical engineering in a successful safety program will be presented by Harold L. Miner, formerly with the Du Pont Co., F. A. Van Atta of the National Safety Council, and George Armstead, Jr., consulting chemical engineer. James J. Duggan of Carbide & Carbon Chemicals Corp., will review fire and explosion protection in hazardous operations. Ample time is scheduled for what is hoped will be informative

Below: The Jayhawk Works of the Spencer Chemical Co. near Pittsburg, Kan. Produces ammonia and other products for industry and ammonium nitrate fertilizer and spensol solutions for agriculture.

GENERAL SESSIONS

Monday Afternoon

W. E. Lobo, presiding

The Application of Radioactive Tracers to Diffusional Operations.—*H. E. Hughes, C. F. Brown Co., and J. O. Maloney, University of Kansas.*

Continuous Extraction in a Multistage Mixer Column.—*J. Y. Oldshue, Mixing Equipment Co., and J. H. Rushton, Illinois Institute of Technology.*

Pressure Loss in Centrifugal Entrainment Separators Under Vacuum.—*E. A. Lawrence, Colgate-Palmolive-Peet Co.*

Low Temperature Vapor-Liquid Equilibria.—*George Brown, Northwestern Technological Institute.*

Product Distribution in Catalyzed and Uncatalyzed Batch Hydration of Ethylene Oxide.—*P. S. Davis, C. E. Van Waaden, and F. Kurata, University of Kansas.*

Tuesday Afternoon

J. O. Maloney, presiding

The Use of Brazing Aluminum in Heat Transfer Equipment.—*H. C. Rooks, Trane Co.*

The Mechanics of Fluidization.—*W. W. Niven, Jr., Tage A. Mortensen, and Albert V. Malone, Midwest Research Institute.*

Bubble-Plate Efficiencies in Ethanol-Water Fractionation.—*G. D. Shilling, G. H. Beyer, and C. C. Watson, University of Wisconsin.*

The Corn Wet Milling Industry—Developments in the Wet Starch Process.—*Robert C. Reck, Corn Products Refining Co.*

The Corn Wet Milling Industry—Developments in Dextrose Refining.—*W. S. Dougherty, Corn Products Refining Co.*

Monday Night

On Monday evening five bull sessions are scheduled. Subjects of informal discussion and the respective leaders are as follows:

The Roll of the Research Institute and University in Industrial Research.—*C. N. Kimball, Midwest Research Institute.*

Methods of Selecting and Training Management Timber.—*W. T. Nichols, Monsanto Chemical Co.*

Applying the Dollar Sign to Process Development.—*R. A. Kinckiner, Du Pont Co.*

What Changes Can the Engineering College Make in its Curriculum to Help Graduates Most?—*R. C. Ernst, University of Louisville.*

What Is Your Plant Doing About Industrial Waste Disposal?—*R. D. Hoak, Mellon Institute.*

discussion of the papers and the general subject of safety.

Symposium: Light Hydrocarbons

This Tuesday morning symposium, with Harold Legatski of Phillips Petroleum Co. presiding, will consist of four papers. Forrest E. Gilmore and Robert D. Bauer of Phillips Petroleum Corp. will discuss the recovery of liquids from catalytic cracking. A review of modern advancements in Hypersorption design will be given by Clyde Berg of the Union Oil Co. The recovery of sulfur from hydrogen sulfide, as discussed by Bernard W. Gamson and Robert H. Elkins of Great Lakes Carbon Corp., should be of particular interest in view of current sulfur shortages. An explanation and corrections for the corrosion problem in amine systems for gas-sweetening will be presented by K. L. Hujsak, G. R. Davis and E. C. Carlson of the Stanolind Oil and Gas Co.

Symposium: The Effect of Company Finances on Engineering Expansion

This symposium, also scheduled for Tuesday morning, will be in the form of a stockholders' meeting for the purpose of discussing and voting on a proposed expansion program. Using as a hypothetical case an expansion to cover the production of sulfur from hydrogen sulfide in fuel gases, the meeting will show what information must be considered by an administrative board in its decision to authorize a project.

Here is an opportunity for all attendants at the symposium to be "stockholders." John R. Riley, Jr., of the Spencer Chemical Co., will act as "president." Viewpoints to be covered and the respective "vice-presidents" are: *Financial*—John P. Miller, Spencer Chemical Co.; *Sales*—Samuel L. Nevins, Mathieson Chemical Co.; *Production*—Loren P. Scoville, Jefferson Chemical Co.; *Research and Development*—C. C. Crawford, Phillips Petroleum Corp.

Symposium: Petroleum Refining

R. M. Cash of the Standard Oil Company (Indiana) will preside over the Wednesday morning symposium on petroleum refining. Metals-poisoning of fluid cracking catalyst will be the subject of a discussion by B. J. Duffy and H. M. Hart of Standard Oil Company (Indiana), to be followed by a discussion of the regeneration characteristics of cracking catalyst by G. M. Webb and M. J. Den Herder, also of Standard of Indiana.

High-vacuum distillation and the thermal cracking or visbreaking of high-vacuum residuum will be discussed by J. G. Allen, D. M. Little, and P. M. Waddill of Phillips Petroleum Co. Catalytic high-pressure hydrogenation of crude shale oil will be reported by M. G. Pelipetz, M. L. Wolfson, and E. L. Clark of the Bureau of Mines. John G. Ditman of the Foster Wheeler Corp. reports on the stepwise extraction of asphaltic residue with propane in comparison with countercurrent extraction.

Symposium: Ammonia Synthesis

The symposium on ammonia synthesis scheduled for Wednesday afternoon is of particular significance to the increasingly fertilizer-conscious Midwest. Homer Kieweg of Commercial Solvents will preside. H. A. Tuttle of Chemical Construction Corp. will discuss several considerations pertaining to ammonia synthesis, including the use of hydrocarbon gases and the choice between thermal cracking and catalytic reforming. W. W. Yeandle and G. F. Klein of Spencer Chemical Co. will review the necessity for high-purity synthesis gas mixtures and the commercial processes for attaining purification. Various ammonia synthesis converters operating in the range of 350 atm. will be compared by L. B. Hein of the Tennessee Valley Authority. High-pressure (1000 atm.) ammonia synthesis will be discussed by H. L. Thompson, Mississippi Chemical Corp., Pierre Guillaumeron, L'Air Liquide Societe, and N. C. Updegraff of the Girdler Corp.

If, as expected, sufficient interest is found at the meeting, a bull session will be scheduled for Wednesday evening to permit further discussions of ammonia synthesis.

Visitors to these sessions should come prepared to participate actively in the discussions.

(Continued on page 44)

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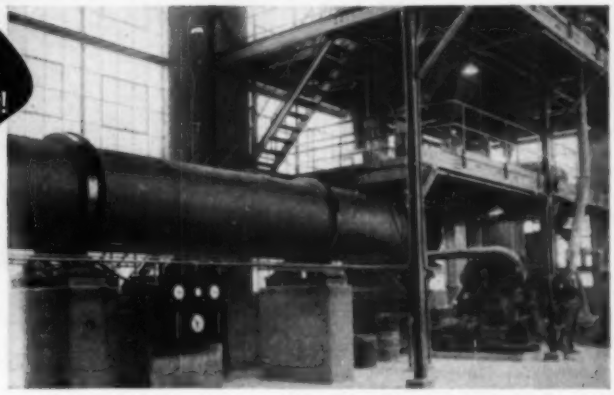

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WHITE SNOWBOUND SPRINGS

TOWARD the end of the recent White Sulphur Springs meeting, one of the visiting chemical engineers looking out at the beauty being created by a surprise March snowstorm remarked that "the weather committee and the scenery committee had an argument, and the scenery committee won."

Such was the case, for the outstanding beautiful grounds of The Greenbrier Hotel, where the Institute met March 11-14 as guests of the Charleston (W. Va.) section, were made even more attractive by a calm six-inch snowfall which began on Tuesday of the meeting week. Acres of shrubs, trees, and lawns lent themselves to views that had all cameras clicking—fit subjects for next season's Christmas cards. Prior to the snow, the 600 chemical engineers had several days of vernal weather for sparetime golf, riding, and casual strolling, and though the snow halted most outdoor sports, complaints were not forthcoming—for the hours spared from an outstanding technical program were well filled by an active entertainment committee.

The continuing experiment of the A.I.Ch.E. program committee to hold at least one resort-type meeting a year, begun in 1948 at French Lick, and continued last year at Swampscott, proved its value again. The experiment at this meeting was multiple. A minimum of papers was offered by the program committee, and authors were alloted an hour and a half for presentation and discussion. A single theme connected each presentation, that of the relationship between pilot-scale and commercial chemical engineering equipment. Another feature, an innovation, was the availability of preprints of all articles. Put up in book form, the preprints were sold for $2.50, and made available ahead of the meeting. All events combined to produce thoroughgoing technical sessions. Authors had sufficient time to present and explain their themes to an audience already familiar with the written paper. Discussion followed the same pattern, with an informed audience seeking and getting answers. The technical pace, while more leisurely, was also more thorough.

All those interviewed during the stay at The Greenbrier were firm in the opinion that the meeting had more than proved its value. Postmeeting-information sessions were held in comfortable meeting rooms and lounges, and since all the engineers were under one roof and eating in one dining room, friends and associates were accessible for conferences.

Preprints of the symposia are still available from the Institute and can be purchased for $2.50 by addressing the Secretary at 120 East 41st Street, New York 17, N. Y. All nine articles are included.

The award for the best presented paper at the meeting was won by Professor J. H. Rushton of the Illinois Institute of Technology.

Entertainment

The local committee to insure even more sociability than already fostered by the surroundings, planned two parties. The first was an informal cocktail party held Sunday evening before dinner. The second event was the "Greenbrier Derby" featuring movie projected horse races. Each person was presented with a sum of play money on entering the room, and wagers could be made on eight different horses. Those fortunate enough to have a "bank-roll" after the fourth race, could then bid on prizes which were auctioned off.

In addition to those get-together parties, bridge and canasta games were featured each evening.

The chemical engineers were welcomed by A. B. Stiles of Du Pont Co. and chairman of the Charleston Section of A.I.Ch.E. In his introductory remarks Mr. Stiles laid stress on the natural resources of the Kanawha valley and the chemical industry that had grown there as a result. At one point of his address he said,

> An indication of the tremendous quantities of the raw materials in this reserve, we shall sight a few data taken from the Geological survey of West Virginia. 120 billion tons of coal in the four better seams of coal; 13 million barrels of oil; gas—one-half trillion cubic feet; salt brine—800 million tons. Coal is our chief resource, and there are in reserve in the five better seams, sufficient coal to last at the present mining for over 800 years. In addition to this quantity of coal there is located in lesser seams at least an additional quantity which should be made available by underground gasification methods.
>
> In addition to fuel, it is also necessary for the chemical industries to have abundant water supply and the Kanawha River fills this need. The Kanawha is and was important to the industrial rise of the Charleston area, as it first provided access to the area, and later provided water power and transportation for the raw materials and products of the manufacturing community.

(*Continued on page 22*)

The group turned out en masse for the Greenbrier Derby, and shown here is a part of the group that attended.

Behind the scenes of the meeting—facilities in projection booth. Left: William Worsham, Greenbrier Hotel, who had charge of sound and projection on movies and slides. Right: William Van V. Bacon, Food Machinery & Chemical Corp., S. Charleston, who helped with the tape recorders, shown in front of him. Recordings were made directly from the control board of the public address system.

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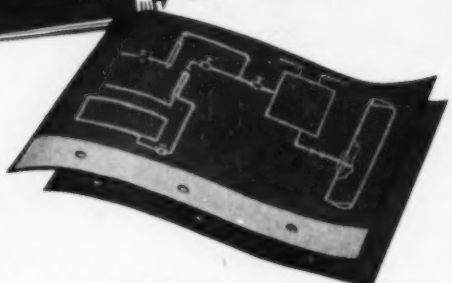

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White Snowbound Springs

(*Continued from page 20*)

W. E. Lobo, M. W. Kellogg Co., New York.

A. B. Stiles, DuPont Co. Inc., Charleston.

J. B. Jones, DuPont Co., Inc., Elsmere, Del., presenting his paper in Session No. 4.

J. H. Rushton, Illinois Institute of Technology, Chicago, won the award for the best presented paper.

W. R. Marshall, Jr., University of Wisconsin, Madison, discussed paper by Blank and Zamzow, at great length.

R. B. MacMullin, R. B. MacMullin Associates, Niagra Falls, discussing paper presented by J. A. Kenney, on "Filtration."

C. R. Ambler, The Sharples Corp., Philadelphia, speaking on "Centrifuge Performance."

G. T. Skaperdas, M. W. Kellogg Co., New York, presiding at Session No. 5.

A. G. Blank, Proctor & Schwartz, Inc., Philadelphia.

Emanuel Singer, Shell Development Co., Emeryville, Calif., delivering his paper on "Scaling-up a Catalytic Reactor."

(*Continued on page 24*)

Turbo-Topics

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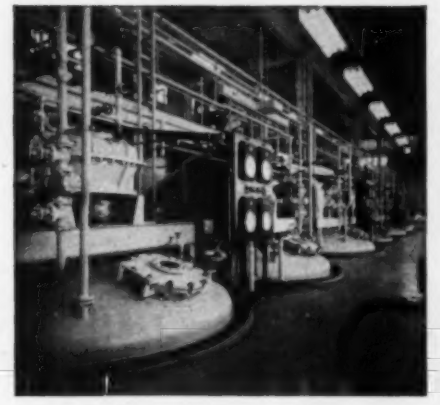

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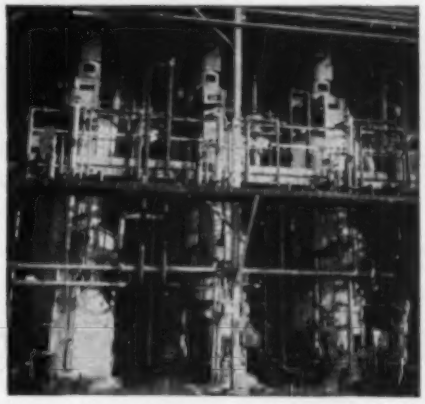

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White Snowbound Springs

(*Continued from page 22*)

Mr. Stiles described the first large industry in the valley which began in 1797; that of concentrating salt brines from salt springs to make salt for the area west of the Allegheny Mountains. This enterprise declined after 75 years, but left behind many solid technical advances, he asserted, and one of these was the technique of well-drilling. Salt producers had drilled to a depth of 1700 ft. as early as 1845, and the methods that they worked out were used by Colonel Drake in bringing in the first oil well.

A trust which the salt producers formed, Mr. Stiles continued, sponsored the development also of a grate to burn coal used to produce the heat for concentrating the salt, "and the first multiple-effect evaporators were in operation in the valley as early as 1833, eight years before its known use anywhere else in the world."

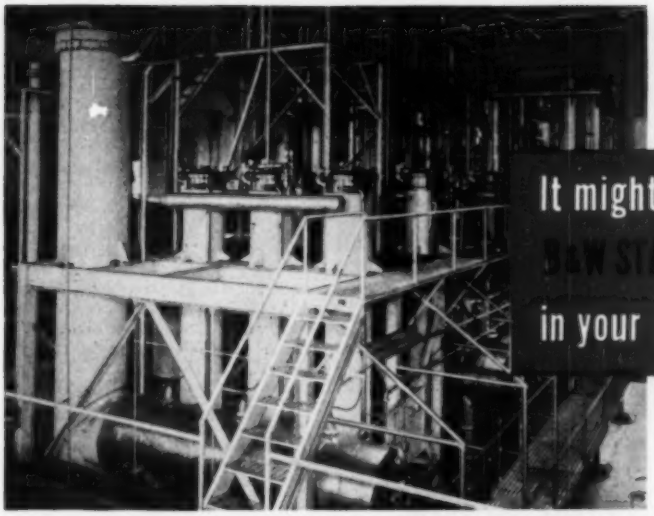
"Here too," he said, "bromine was produced from brines, and a production of 30,000 lb. per year were recorded as early as 1868."

Toward the end of his talk Mr. Stiles touched on products being made at present in the Kanawha Valley. Mr. Stiles contrasted the defunct salt industry, with the present prosperous chemical industry which utilizes the abundant raw materials. He said:

There is now located in the Kanawha Valley a diversity of chemical industries producing materials which are sold throughout the world. The General Food Machinery Co. produces from salt brine chlorine, caustic soda and related products by electrolysis. This plant is reported to have under a single roof the largest number of chlorine cells anywhere in the world. The natural gas which was such a boon to the original salt manufacturers has been the backbone of the ceramic, lead oxide, and other chemical industries. The largest plate glass plant in the world, and one of the largest bottle plants are located here. Natural gas and petroleum are the raw materials from which ethylene glycol, ethanol, acetone, and a host of derivatives are produced by Carbide & Carbon Chemicals Corp. Coal is the basic material from which duPont produces ammonia, methanol, nylon, and many other chemicals which were once rare or unknown. . . . Other industries which are utilizing abundant resources are the American Viscose Co., Monsanto Chemical Co., Ohio-Apex Co., Goodrich Rubber Co., Pure Oil Co., and the Elk Refining Co.

Top left: T. H. Chilton, President, A.I.Ch.E., and Mrs. Chilton. Top right: D. S. Bruce, Hercules Powder Co., Parlin, N. J., and Mrs. Bruce. Middle left: Curry E. Ford, National Carbon Div., Cleveland, Ohio, and Mrs. Ford. Middle right: C. R. DeLong, Treasurer, A.I.Ch.E., and Mrs. DeLong. Bottom left: W. I. Burt and Mrs. Burt. Bottom right: R. C. Gunness, Standard Oil Co. (Indiana), Chicago, and Mrs. Gunness.

Top to bottom: J. E. Crawley, Jr., and G. B. Bradshaw, Jr., DuPont, Belle, W. Va.; J. H. Howell, Carbide & Carbon Chemicals Corp., Charleston, J. R. McClain, and James F. Roe, Monsanto Chemical Co., Nitro (Roe & McClain on Plant Visits Committee); R. V. Green, Registration Committee, DuPont, Charleston, S. D. Smith, Sports Committee, DuPont, Charleston, H. M. West, Program and Papers Committee, Carbide & Carbon Chemicals, Charleston, and D. G. Hulett, Entertainment Committee, Carbide & Carbon Chemicals, Charleston; M. L. Sims, Ohio-Apex, Inc., Nitro, M. M. Delancey, DuPont, Charleston, J. H. Howell, Carbide & Carbon Chemicals, Charleston, and B. T. Woodruff, DuPont, Charleston; J. K. Harvey, Transportation Committee, Carbide & Carbon Chemicals, Charleston, K. J. Gutshaw, Carbide & Carbon Chemicals, Charleston, and R. J. Valleau, Registration Committee, American Viscose Corp., Nitro.



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There most certainly is such a thing as guaranteed performance. Every piece of Proctor drying equipment sold has a guaranteed performance rating written into the sales contract. The equipment must perform according to this guarantee before Proctor engineers consider their work completed.

Guaranteed performance is possible for Proctor equipment because nothing is left to chance at any stage in its development. A Proctor representative will talk with you the moment you realize you need drying equipment . . . will help you establish your requirements in specific terms . . . will assist you in considering preliminary and subsequent processing so that drying becomes an integrated part of the over-all process . . . will work closely with you as test work proceeds either in Proctor laboratories or your own plant . . . and will be in constant touch with the engineering, building, and installation of your equipment.

Guaranteed performance is no mere advertising phrase . . . but is exactly what you buy when you specify Proctor "job engineered" drying equipment.

The next time a drying problem presents itself—remember you can buy guaranteed performance by calling Proctor engineers into the picture early!

For the complete story of the Proctor approach to solving drying problems, write for Bulletin 361. For a lucid explanation of Proctor Drying Systems for the Process Industries, ask for Bulletin 342 as well.

A FEW TYPICAL MATERIALS BEING DRIED IN PROCTOR CONTINUOUS CONVEYOR SYSTEMS

Starch
Titanium Dioxide
Sulfa Drugs
Calcium carbonate
Magnesium carbonate
Clay
White Lead
Finished Lithopone
Soy Bean Protein
Lead arsenate
Nitro guanadine

PROCTOR CONTINUOUS CONVEYOR SYSTEMS

PROCTOR & SCHWARTZ INC • 630 TABOR ROAD • PHILADELPHIA 20 • PA •

NATIONAL INVENTORS COUNCIL REACTIVATED

According to Charles F. Kettering, chairman of the National Inventors Council of the Department of Commerce, the agency has been reactivated for assistance to military research. The N.I.C. is the agency within the federal government which links civilian invention and military research.

Through the U. S. Department of Commerce, the Council offers an information bulletin on procedures for submitting proposals.

According to the Council, eight of the problems which will help the national defense, are as follows:

1. An insect repellant of a type suitable for application by the individual which will effectively repel all insects for a period of 24 hours or more with a single application.
2. A cloth-like material possessing ballistic protection which is lightweight, flexible, and not bulky.
3. A means of individual protection from gamma radiation.
4. A method for prolonging the preservation of whole blood.
5. An accurate instrument and technique for barometric leveling.
6. A technique, method and equipment for the detection of buried explosives.
7. Rapid, automatic methods of determining the size of smoke particles and the obscuring power of the smoke.
8. Methods for dispersing liquids and solids as a stable aerosol and not decompose the material being dispersed.

COAL GASOLINE PLANT FOR SOUTH AFRICA

Construction of a commercial, gasoline-from-coal synthesis plant will start in South Africa within the near future, The M. W. Kellogg Co. states.

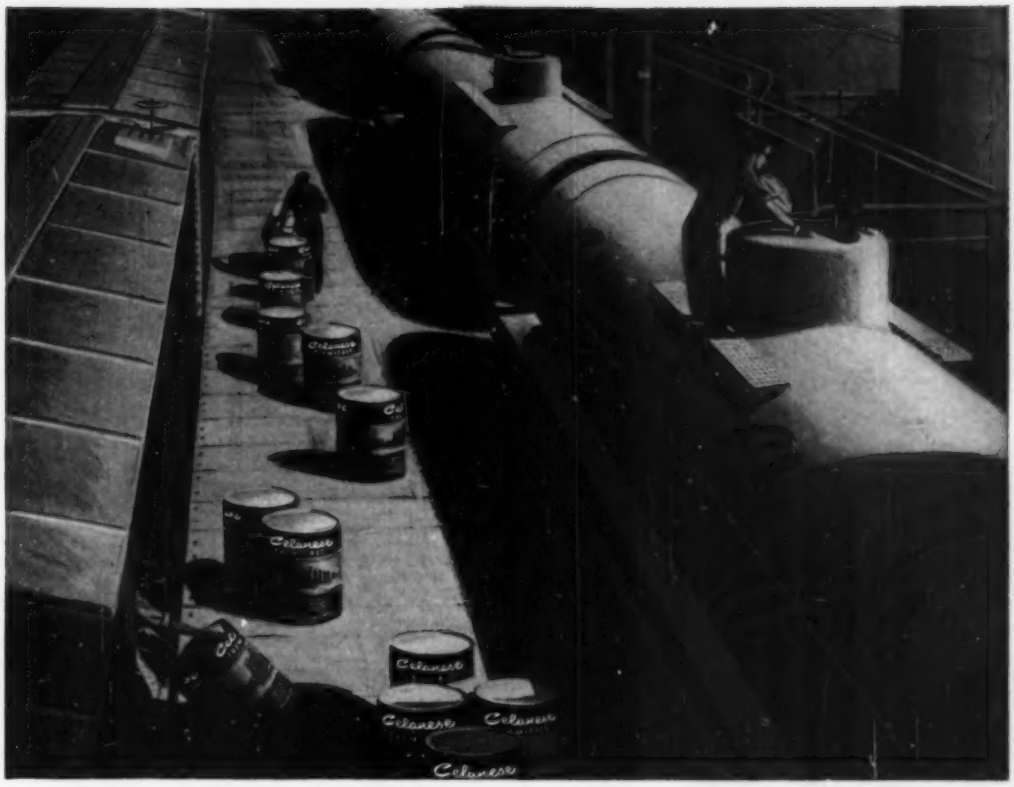
The plant is being built for SASOL —South African Coal, Oil and Gas Corporation Ltd. It will be located about 40 miles south of Johannesburg.

The project will use new coal deposits to supply raw material and above-ground gasification facilities to transform coal into synthesis gas will be built.

Kellogg's Synthol process is to be utilized in the synthesis.

COLD RUBBER OUTPUT BOOSTED

Production of cold rubber at the Port Neches (Tex.) plant, B. F. Goodrich Chemical Co., operates for the government will be increased 50 per cent shortly, W. I. Burt, vice-president of manufacturing, announced recently. He said the government has authorized the installation of refrigeration equipment costing $350,000 to expand cold-rubber production from 30,000 to 45,000 tons of the plant's 60,000-ton annual rated capacity.



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The Celanese Chemcel plant near Bishop, Texas, is operating 'round-the-clock to meet these growing demands of defense and heavy industry . . . producing Formaldehyde, Acetone, Acetic Acid and other vital organics by the direct oxidation of natural petroleum gases in the district.

Celanese chemical service includes expanded plant facilities employing the most recent developments in chemical production . . . a reliable source of raw materials virtually on the plant's doorstep . . . a nation-wide distribution system . . . research laboratories and pilot plants . . . and valuable technical assistance based on a generation of experience in petroleum chemistry—assurance to industry of large-scale uninterrupted production.

REVISED FORMALDEHYDE TECHNICAL MANUAL

Write now for the revised technical manual on Formaldehyde—37 pages of detailed information, including a special 4-page section on Formcel† (Formaldehyde—alcohol solutions). Celanese Corporation of America, Chemical Division, Dept 507-D, 180 Madison Avenue, New York 16, N. Y.

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*Reg. U. S. Pat. Off. †Trademark

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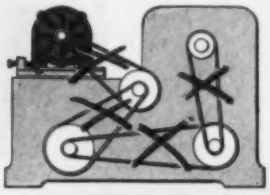
CUMBERSOME

COSTLY HOOK-UPS



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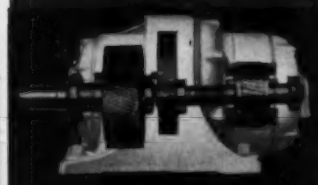

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You can eliminate the nuisance and expense of belts, guards, chains and sliding bases used with standard motors to get low speeds. Syncrogear with internal gearing permits direct drive, simplifying installation. Saves space, too!

¼ to 30 hp.

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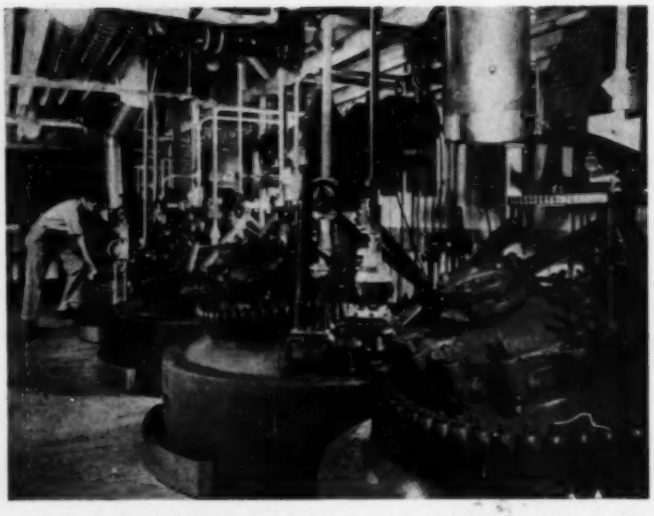


Above is a scene from the production line of the Charles Pfizer & Co., Inc., plant at Groton, Conn., for the production of crystalline vitamin A. Production of this vitamin on a commercial scale was first announced last month by John E. McKeen, president of the company at a press conference at which he stated that synthetic crystalline vitamin A acetate had been successfully produced on a commercial scale, and that at full capacity the Groton plant would produce 50% of the total U. S. civilian and military need for vitamin A.

To prevent oxidation of the vitamin, all equipment is airtight and processing takes place in the absence of air.

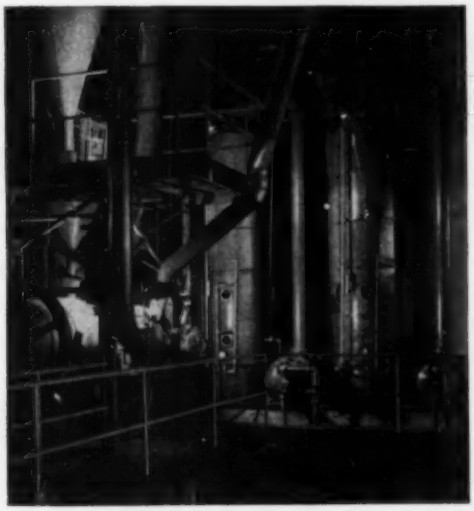
The vitamin is being made available as dry synthetic crystals, as a stabilized powder, and as a liquid.

According to Mr. McKeen, Pfizer research scientists have perfected a process which stabilizes crystalline vitamin A by coating the crystals with gelatin.

At the first regional conference of the chemical engineering division of the Chemical Institute of Canada at Toronto, Feb. 19-20, were (left to right): H. R. L. Streight, chairman of the division and of the conference; H. B. McGuffie, National Research Council, Chalk River; T. H. Chilton, President, A.I.Ch.E., and A. Monsaroff, secretary-treasurer of the division and of the conference. Dr. Chilton gave an address to the delegates on the development of unit operations in the last ten years. He is also technical director, development engineering division, DuPont Co.

A Headline that is also a Helpline!

1 BUFLOVAK Evaporators 2 Profitably used for By-Product Recovery 3 Produce Salable Products from Waste Materials 4 Which Put Dollars in Your Pocket 5 And Solve Disposal Problems



The above illustration shows BUFLOVAK Evaporators used in the recovery of zinc sulphate and zinc chloride from pickle liquor. The evaporators are equipped with patented Salt Separators.

1. BUFLOVAK Evaporators are engineered to profitably meet the individual plant condition and built in many types, sizes and materials of construction.

2. They are successfully used for the recovery of by-products; such as, stillage, pickle liquor, black liquor, whey, mercerizing liquor, sulphite waste, steep water, and other valuable wastes in many industries.

3. Such products are converted into salable or reusable materials by efficient evaporation methods. Some by-products are also dried with BUFLOVAK Equipment.

4. It's a new source of added profits. And, it puts additional dollars in your pockets through savings in steam and cooling water, that come from multiple effect evaporation economies.

5. Disposal problems are profitably solved; and stream pollution is prevented.

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DIVISION OF BLAW-KNOX CO.

RESEARCH AND TESTING LABORATORY

To assist you in the solution of processing problems, BUFLOVAK offers the facilities of its Research and Testing Laboratory ... where small scale experimental units show you, before you buy, the commercial possibilities, data on production cost, and characteristics of the finished product.

MARGINAL NOTES

News of Books of Interest to Chemical Engineers

Plain English for Textile Finisher

An Introduction to Textile Finishing. J. T. Marsh. John Wiley & Sons, Inc., New York, N. Y. (1951) 552 pp. $5.50.

MR. MARSH, who is not identified anywhere as to his connections or company, nevertheless supports his competence to write a book on textile finishing in his Preface, which is well written and enjoyable to read. He speaks of his acquaintance with the famous finishing installations in the United States, Canada and Europe, and of his good fortune to be acquainted with many of the pioneers of textile science. In this book Mr. Marsh has attempted to cover all the phases of finishing in its widest sense.

The book is written with an English slant and with English connotations, but it is well illustrated and should not prevent anyone connected with the field from understanding exactly what is meant in all cases. An adequate description is given of all textile-finishing machines and covers all other aspects such as crêping, mercerizing, etc. However, the book is not limited solely to the mechanical finishing operations, and there is a good deal said about chemical treatment. A section on synthetic resins covering urea, formaldehyde condensate, crease-resisting processes, is typical of the chapters in this work.

Its modernity is attested by the section on rubber, and impregnation of materials with it, which ends up with a brief résumé of synthetic rubbers. Processes such as mildewproofing, waterproofing, and fireproofing are also covered.

While the book is termed an introduction and can be read with value by those not acquainted with the field, its completeness recommends it to those in the textile field who wish to have a recent work on the subject.

Statistics That Don't Lie

Technological Applications of Statistics. L. H. C. Tippett. John Wiley & Sons, Inc., New York, N. Y. (1950) 189 pp. + vii. $3.50.

Reviewed by Vernon E. Lewis, Assistant Professor, University of Delaware, Newark, Delaware.

STATISTICS is a branch of mathematics which has been developed to aid in understanding the facts behind numerical data. In a real sense, then, it becomes a tool for the worker in technological fields, and becomes most useful in the hands of the worker. Just as a beautifully made tap is not useful in the shop window of a toolmaker but becomes useful in the hands of a machinist, so statistics is not useful in the hands of the toolmaker (the mathematical statistician) but becomes tremendously effective in the hands of the user (the technical worker). Mr. Tippet's book has been written around this idea. He does not attempt to teach the reader how to become a mathematical statistician. Rather he attempts to give the reader an understanding of the purpose, the proper method of use, and the limitations of the various statistical methods as they have been developed by the mathematicians. Then he goes on to show how these methods can be used to obtain more clearly and efficiently the answers to the questions which led to the taking of data.

The methods are illustrated by worked-out examples on numerical data in various technical fields. The examples, with their explanatory text, should be understandable by any competent technical worker, even though they will not, in general, be drawn from his own particular field. By going through the steps of formulating the question, planning and analyzing the data, and translating the statistical findings back into language which appropriately answers the original question, the reader will develop the "feel" for the methods and the confidence to begin to apply them to his own problems.

The book is a welcome addition to the library of the worker with no statistical training because it will bring him a clear introduction to the subject. It will also be welcomed by the statistician with limited training in technology, because it will help him better to understand the technical man's viewpoint and problems. The author is unusually well qualified to effect this exchange of understanding, because of his recognized competence both as a statistician and as a technologist. It is a matter of slight regret that the original data and discussion of many of his examples occur in British publications, which will make them slightly difficult for many American readers to obtain, but the book stands so well on its own contents that this should not seriously affect most readers.

Informal Textbooks

Principles of Phase Equilibria. F. W. W. Wetmore and D. J. LeRoy. McGraw-Hill Book Co., New York, N. Y. (1951) 200 pp., $3.50.

Reviewed by F. W. Winn, Socony-Vacuum Oil Co., Inc., Paulsboro, N. J.

THIS book presents an informal discussion of heterogeneous phase equilibria. Liquid-liquid and solid-liquid systems are given primary consideration and only a short elementary discussion is given on vapor-liquid equilibria.

Most of the terms associated with the subject are defined and discussed at length. These include: the phase rule and proportioning rule; polymorphs and allotropes; triple, boiling, freezing, and sublimation points; solidus and liquidus curves; and eutectics and azeotropes.

The style used is of an informal nature and much emphasis is placed on logical thinking to arrive at the various concepts. The diagrams are explained clearly and soundly and in this respect the book is excellent. The absence of specific references to the experimental data used to construct the diagrams is a point of criticism, however. Considerable discussion is devoted to the numerous examples and each chapter is followed by a set of exercises which have been designed to teach the subject matter.

The book is well suited as a textbook but for those familiar with the field, other recent works are likely to be more useful.

Fertilizer Grade Ammonium Nitrate. Manufacturing Chemists' Association, Washington 5, D. C. (1950) 23 pp. 50 cents.

PROPER methods of handling, storing and using ammonium nitrate fertilizer, are described in this new booklet. Ammonium nitrate has become one of the most important sources of plant food for agriculture and a group of experts from the Manufacturing Chemists' Association has prepared this guide for use by establishments handling this chemical. The potential hazard of ammoniuum nitrate is acknowledged and several recommendations are made for safe handling and storage.

However, the book does note that this material, like other commodities of everyday use in the city and on the farm, is safe if properly handled.

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"SINGIN' ENGINEER"

John Pfander, a chemical engineer, employed by the Houdry Process Corp., in Linwood, Pa., and by avocation a singer of folk songs is currently being featured on Station WILM in Wilmington, Del., as a ballad singer. He has already built up a substantial listening audience according to WILM from the mail that has poured into the station.

This entertainer on the air from 12:45 to 1:15 P. M. every Saturday with a selection of American folk songs, hails from Missouri, that section of the country which has produced many of our finest ballad singers. He was born on a farm near Jasper in 1925. Following his graduation from the nearby Lamar High School, he attended the summer session of the University of Kansas in the A.S.T.R.P. program. His education was interrupted with a service period in the Army, but October, 1946, finds him picking up the loose ends of his education at the University of Missouri. He received his B.S. in chemical engineering in June, 1950, when he moved east to become associated with Houdry.

Always interested in music, this singing engineer took voice lessons in college and attended the Conservatory of Music in Kansas City. He has been playing and singing whenever he can get anybody to listen. He does admit, however, an interest in chemical engineering, too.

ARIES ASSOCIATES BUYS W. Y. AGNEW BUSINESS

R. S. Aries & Associates, New York consulting chemical engineers, have acquired the business of William Y. Agnew, consulting chemical engineer, also of New York. This acquisition will expand the scope of activities of the Aries organization.

The general engineering and drafting offices of the newly acquired company will remain at 500 Fifth Avenue, New York, while the executive offices will be transferred to the parent company at 400 Madison Avenue, New York. The new acquisition will supplement the existing engineering facilities of the Aries organization located in Brooklyn, N. Y.

A.E.C. WANTS ZIRCONIUM

Plans to encourage wider industrial participation in the manufacture of high-purity zirconium metal for the nuclear reactor development program have been announced by the Atomic Energy Commission. At the present time, zirconium metal meeting required chemical and physical specifications is being produced largely in Government-owned or-controlled facilities, using processes developed by the Bureau of Mines and contractors of the A.E.C.

The major steps now used in obtaining pure metal from the commercial grade zirconium tetrachloride are:

1. Separation of hafnium from crude zirconium tetrachloride.
2. Chemical purification of separated zirconium.
3. Calcination and rechlorination of purified zirconium.
4. Reduction of purified tetrachloride using basic Kroll-type process.
5. Refining of the reduced metal, using the basic deBoer-type process.

Technological information about these unit processes may be made available to private producers and classified information can be made available to interested producers following security clearance.

Manufacturers interested in the A.E.C. zirconium purchase program should write the Division of Engineering, Atomic Energy Commission, Washington 25, D. C.

IS THAT ADDRESS CHANGE NECESSARY?

We have noticed that many change-of-address requests involve merely a switch from business to home and vice versa, though the subscriber has not actually left his former business affiliation. Since there is a shortage of the metal used in address stencils, readers can help us conserve a diminishing supply of these plates by withholding unnecessary requests for address changes.

INTRADEX TO BE MADE IN U. S.

A sugar-derived substitute for blood plasma which is now being sold in Great Britain and several other countries will shortly be made in the United States according to T. C. Usher, managing director of Dextran Ltd., of Darlington, England, who is now in the United States.

Plans are under way for a plant costing approximately $700,000 which will be located in Orange, N. J., through the founding of a new organization tentatively known as Tell & Usher, Ltd. The new organization will be effected through the association of T. C. Usher, and Philip Tell of the Tell Manufacturing Co., Orange, N. J.

The product is known as Intradex and is described as a solution of dextran "specially prepared and possessing to a high degree the ideal properties desirable in a blood plasma substitute."

According to Mr. Usher, the United States plant will be built and in operation within nine months. Initial production calls for 20,000 units per month. A pharmaceutical house, as yet unnamed, will handle distribution.

Although Dextran is not a substitute for whole blood it is widely accepted in cases where plasma is needed. It can be shipped by sea, rail or air without change in its properties and does not need to be kept at any particular temperature when stored in an emergency stockpile.

NEW PRESSURE PIPING CODE

A new and revised copy of the American Standard Code for Pressure Piping, is announced by the American Society of Mechanical Engineers. Approval of the revised standards was given in February of this year by the American Standards Association. The code is being made available by the A.S.M.E. for $3.50 as the work of Sectional Committee B31.

The first standard pressure piping code was published in 1942 by the A.S.M.E. though it had been preceded by several tentative standards first published in 1935 and 1937. The work on the new code was done under F.S.G. Williams, chairman of the Sectional Committee.

The code covers power piping, gas and oil, district heating, refrigeration, and fabrication details. Sections on materials, fittings, and list of codes and standards round out the volume.

GRADUATE ASSISTANTS OPEN AT MICH. STATE

Half-time graduate assistantships are available in the department of chemical engineering at Michigan State College. The stipend is $1000 for the academic year; tuition and fees are waived. Holders of these assistantships will normally be able to complete the requirements for the M.S. degree in two years. Letters of application together with transcripts of previous academic work should be forwarded to Professor R. W. Ludt, acting head, chemical engineering department, Michigan State College, East Lansing, Mich.

WASTE COMMITTEE ISSUES REPORT

Industry is making definite progress toward more effective control of wastes which contribute to the pollution of the nation's waterways, it was reported recently to the National Technical Task Committee on Industrial Wastes meeting in Cincinnati.

The Committee whose chairman is Lyman Cox, supervisor, engineering service division, Du Pont Co., Wilmington, Del., was organized at a meeting at Washington, D. C., May 9-10, 1950. The Committee at that time drew up an outline of an Industry-Government approach in the solution of industrial waste problems. It was agreed then that its purpose would be "to effect an improvement in the quality of water resources in the Nation," and that it would undertake "to perform technical tasks pertaining to industrial wastes in cooperation with the Public Health Service and all others."

The initial tasks agreed upon were to: (1) assemble a list showing sources of information on processes and practices known for using, treating and controlling industrial wastes; (2) assemble a tabulation of research projects concerned with utilization, treatment and disposal of wastes, those underway and those contemplated; (3) provide a list which will define problems that confront a given industrial group and for which there is no satisfactory solution.

Special reports were made at Cincinnati covering four industrial groups. L. C. Burroughs, Shell Oil Co., New York, covered the coal, coke, iron, steel and petroleum industries and said:

One of the most difficult problems of the by-products coke industry is the disposal of waters containing phenols, cyanides and oily wastes. To handle phenols a large new dephenolizer has recently been placed in operation and several older units have been modified to increase their efficiency.

This industry is following closely the efforts of other industrial groups to solve similar problems. The cyanide problem, while of lesser importance industry-wide, is subject to an extensive research program, and an industrial size process demonstration plant has been constructed for recovery of cyanides at a by-product coke plant.

Cooperative waste disposal work in the oil industry is concentrated largely in the American Petroleum Institute's Committee on Disposal of Refinery wastes, Mr. Burroughs added.

Dr. Harry Gehm, technical director, National Council on Stream Improvement for the Pulp, Paper and Paperboard Industries, New York, reported for the chemical processing industries and recommended that the Public Health Service at Cincinnati make fundamental studies on problems such as the thickening and dewatering of hydrous residues obtained in treatment of some wastes.

CHIKSAN

Hydraulic Swivel Joints help to simplify design

Hydraulic line fully extended, with turning movement taking place with CHIKSAN Swivel Joints.

As the Unpacker Head travels back and forth, the hydraulic line folds and unfolds automatically.

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With CHIKSAN Hydraulic Swivel Joints you can design and build flexible hydraulic lines to handle pressures to 3,000 psi . . . and thereby gain advantages not obtainable by any other method. A typical example is the *Ermold Automatic Case Unpacker.*

CHIKSAN Hydraulic Swivel Joints make possible sharp bends, thus permitting installations where space is limited. They eliminate drag and snag. In addition, you get uniform low operating torque, strength and safety under all conditions. All-metal tubing assures longer life.

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Chemical Engineering Progress

DATA SERVICE

BULLETINS

1 • STAINLESS TUBING DATA. A slide rule on stainless tubing from The Carpenter Steel Co. which gives on one side, data about the compositions of 16 stainless alloys, also strength, properties and other physical data, plus a chart of bursting pressures. The other side of the slide rule gives the desirable bending and coiling radii for stainless tubing and pipe. Standard dimensions and standard sizes for round tubing are shown on charts.

2 • 3 • WESTINGHOUSE BULLETINS. Bulletin (2) describes Precipitron electronic air cleaners in nontechnical language. The Precipitron is a Westinghouse device for cleaning air by electronic methods and is intended for heating, ventilating, air-conditioning, etc. Bulletin (3) describes a new line of d.c. motors and generators. Construction details are described, all features of windings, brushholders, etc., shown. Explosion-proof types are available as well as totally enclosed fan-cooled models.

4 • VARIABLE SPEED DRIVES. A bulletin describing basic operating principles of a variable speed drive by Reeves Pulley Co., plus rating tables, dimension drawings and supplemental equipment for use on three basic units.

5 • MAGNETIC HUMP. A permanently magnetized tramp iron trap is described by Eriez Manufacturing Co. Designed to remove tramp iron from materials conveyed pneumatically or in slurry and liquid lines, or gravity flow materials. The hump is designed to take advantage of the inertia between magnetizable material and material to be cleaned. Full illustrations, dimensions, etc.

6 • NEUCLEONICS PRICE LIST. An illustrated price list from Tracerlab, covering such divers items as scalers, accessories, sample holders, safety equipment, Geiger counters, etc.

7 • ALUMINIZED STEEL. For engineers in the chemical field concerned with construction, a new booklet of Armco Steel Corp. illustrates a new steel-aluminum surface metal. Shows properties and installations that can utilize the product, such as fan walls in kilns, louvers for combustion chambers. Some data on heat reflectivity, corrosion resistance, chemical properties, weights, methods of finishing, welding, etc.

8 • HIGH-PRESSURE PUMP. Deming Co. announces a new multistage high-pressure centrifugal pump for general industrial noncorrosive liquids; 2-3-4 and 5-stage construction. Pump and motor are one unit. Vertical type. Capacities range from 10 to 45 gals./min. against heads up to 400 ft.

9 • ENGINEERING EQUIPMENT. An illustrated booklet from Wellman Engineering Co. showing the engineering equipment the company makes. For those who need skip hoists, bridges, buckets, cars, dumpers, charging machines, coke-oven machinery, furnaces, gas producers, gas-reversing valves, gas generators, cranes, hoists, or coal and oil-handling equipment.

10 • DIMENSIONAL DATA CARD. For the essential dimensions of welding fittings and flanges Taylor Forge & Pipe Works offers a data card which condenses data on wall thickness and essential dimensions for all types of fittings for all nominal pipe size from ½ in. through 30 in. The other side of the card has on it data about forged steel flanges giving essential dimensions, and bolting data, etc.

11 • CORROSION-RESISTANT COATINGS. A wall chart of materials that are acid and alkali resistant made by Heil Process Equipment Corp. Tells uses, resistance, application, coverage and packaging of several different materials—tank linings, plastics, paints, vinyl coatings, cements, etc.

12 • FLANGE AND COUPLING SELECTOR. A Nooter Corp. flange and coupling selector in slide rule form which gives data on diameters, thickness, bolt circle, etc., for flanges and sizes of couplings available, plus pipe standard tables.

14 • VISCOSITY DETERMINATION. From Fischer & Porter Co. a new catalog describing Viscorator instruments which provide an instantaneous method of determining viscosity values. A new development provides a constant meter sample flow rate regardless of line fluctuations. Bulletin explains engineering details and facts of the measurement.

15 • ROTATING EVAPORATOR. Rodney Hunt Machine Co. describes and shows engineering features of Turba-Film evaporator for use in

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the chemical, pharmaceutical, food, etc. industries. Units available in sizes up to 2500 lbs. of water evaporation/hour. Evaporator requires only seconds for passage and evaporation. Features a jacketed vertical tube and a rotated evaporation center. Plant layouts are shown utilizing evaporators.

16 • CORROSION OF CONDENSER TUBES. An extensive and well-illustrated report on corrosion factors in condenser tubes by Revere Copper & Brass, Inc. Report covers corrosion of tubes, protective films to prevent corrosion, and describes development work now being done for tube alloys. Photomicrographs of corrosion of various types of metals as well as a story about the Revere organization plus compositions and recommendations of condenser tubes.

17 • PIPE-LINE FILTERS. Dollinger Corp. bulletin on mechanical filter for eliminating water, oil, dirt, etc., from line flow of gases and air, etc. Models, specifications, etc., are all covered.

18 • DRYERS. An illustrated brochure showing Standard-Hersey dryers used in the chemical process industries. Dryer types are listed plus pictorial illustrations and examples of use.

19 • SINGLE-STAGE CENTRIFUGAL. For continuous process service in the chemical field, Pacific Pumps Inc. centrifugal pumps are described in a new brochure. Cut-away views in color show construction and main design features. Two types of pumps with ratings from 1500 to 1660 gals./min. Table of pump size selection and dimensions.

20 • CEMENT LINING PIPES. The Tate process for lining pipes already in place with a smooth cement mortar, described by Pipe Linings, Inc. Essentially the brochure explains the mechanical details of how the steel pipes are scraped and the mortar laid onto pipe walls.

21 • AUTOMATIC STRAINERS. For straining water, ammoniacal liquors, chemical solutions, etc., S. P. Kinney Engineers, Inc., offers a bulletin on Brassert automatic self-cleaning strainers. Strainers from 4 in. to 36 in. pipe-line sizes of special materials. Of interest to chemical, coke, water, etc., plants. Bulletin shows construction, capacities, etc.

EQUIPMENT

25 • VAPE-SORBER. The Selas Corp. of America has an activated carbon adsorber for removing petroleum vapor, dirt and liquids from compressed air and other gases. Ceramic tubes pass only air and gas, and the bed of adsorbing carbon removes the petroleum vapor. Available in capacities of 100 to 500 cu. ft./min. at pressures of 150 lbs. Capacities, dimensions, and description in detailed bulletin.

26 • POCKET pH METER. A pocket-size pH meter and companion probe unit for determining on the spot pH concentrations is offered by Analytical Measurements, Inc. Battery-operated, it comes in a small case and weighs 3 lbs. Meter scales from a pH of 2 to 12 with accuracy to 0.1 unit.

27 • TOOTHED TIMER BELT. United States Rubber Co. has developed the Gilmer timing belt, a rubber and fabric combination with teeth for use on power transmission installations that require accurate timing. For use on instruments, gasoline pumps and industrial equipment where similar units are in simultaneous production.

28 • ADHESIVE SAFETY SIGN. Adhesive labels for mounting on pipe lines, doors, elevators and dangerous places, which come on dispenser cards and are applied without any moisture are offered by the W. H. Brady Co. More than 550 safety signs and pipe markers. Conform to ASA standards.

29 • RADIAL FIN TRANSFER TUBE. Modine Mfg. Co. has developed a new two-fluid heat-transfer surface in the form of a concentric tube with radial fins. For use by the chemical, gas, pharmaceutical, etc., industries. Fabricated from any metal tube, is available in diameters of 1 in. and 1⅜ in. and has six radial fins.

30 • CYCLE TIMER. A new multiple-circuit cycle timer for use in industry for timing furnaces, electrical appliances, laboratory equipment, and pilot plant units. May be set for on-or-off periods with as many circuits as desired. A new product of the Zenith Electric Co.

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31 • FROST PREVENTER. For the prevention of frost in cold rooms, Niagara Blower Co. has developed a "no frost" system. The cold air stream at sub-zero temperature passes over refrigerated coils sprayed with a nonfreezing compound. The nonfreezing compound is removed to a concentrator, the water removed and the reconcentrated material passed back to the spray chamber. Effective to temperatures as low as −30° F. Water evaporating capacity from 1½ to 75 gals./hr.

32 • 33 • VAPOR-TIGHT FIXTURES. (**32**) is a vapor-tight fixture made of a noncorrosible alumalloy for use in the petroleum and chemical process industries. (**33**) Is a complete line of explosion-proof fittings for hazardous locations. Killark Electric Mfg. Co.

34 • TACHOMETER. An inexpensive tachometer to use with variable speed transmissions and motor drives is announced by Reeves Pulley Co. Electrical in operation and more accurate than mechanical tachometer. Designed for quick installation, it operates accurately at long distances from speed drive.

35 • DRUM CLEANER. Two rotoblast drum-cleaning machines for removing dirt, rust, paint, etc., from 30- and 55-gal. steel drums and lids, are announced by Pangborn Corp. Operated by one man, principle depends upon a metal abrasive hurled against both interior and exterior surfaces by centrifugal force. Scours metal clean and surface is ready for repainting. Models will clean either 320 to 560 drums, or 1000 to 1100 drums a day. Cleaning cycle 50 to 90 sec.

36 • GAS ALARM SYSTEM. To protect six to eight separate plant locations a new sampling-type combustible gas alarm system is announced by Davis Emergency Equipment Co. Operation of the unit is based on timed revolving mechanism which draws samples through connecting tubes.

37 • DEIONIZING UNITS. Illinois Water Treatment Co. announces a complete line of package-type deionizing units ranging from 12 to 1000 gals./hr. Includes six sizes of mixed-bed deionizer units producing water containing less than 0.1 p.p.m. total dissolved solids.

38 • HEAT INSULATION. Curved blocks in a complete range of sizes and thicknesses and made of hydrous calcium silicate is announced by Owens-Illinois Glass Co. Range covers tubes and pipes from ¼ in.-D to 72-in. and vessels up to 60 ft. The insulation is effective up to 1200° F. and available in thicknesses from 1 in. to 6 in.

39 • CAUSTIC SODA METER. An all nickel variable flow meter for handling caustic streams is described in a bulletin of the Fischer & Porter Co. Steam jacketed, sizes range from ½ to 300 gals/min. The one moving part, the float, is entirely confined within a liquid system and float movement is picked up by means of a magnetic follower for transmission to a remote receiver.

40 • PACKING INSTALLATION TOOL. Greene, Tweed & Co. have a new packing and packing installation tool for sealing tube sheet closures on heat-transfer equipment for use with corrosive fluids. Company claims a good seal against all leakage and tube sheet closures and a reduced cost in material and installation over conventional seals where bolting or threading are involved. The packing used is of molded composition available to match the service. The tube has been proved to 400 lb./sq.in. on the tube side and the first test installation of 480 seals has been in continuous service without a failure since April, 1948. Complete information available.

41 • PLASTIC FILM TAPES. Two new, specialized plastic film tapes for use by food and chemical industries, are in production by the Minnesota Mining & Manufacturing Co. Both tapes are pressure-sensitive types,—one a polyethylene film, the other a Saran film. They are designed for special package and bottle-sealing jobs in these industries. Used where low moisture-vapor transmission rates are necessary. The polyethylene tape has a maximum elongation of 700%, the Saran tape has a moisture-vapor transmission rate of 0.15 g./100 sq.in./day.

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42 • ***PNEUMATIC TRANSMITTERS.*** A complete new series of pneumatic instruments for transmitting and controlling flow, pressure, liquid level, and specific gravity, is in production by the American Meter Co. Improvements incorporated resulted from a survey among instrument engineers. Improvements such as a reduced number of pivot points and moving parts, utilization of subassemblies and standardized parts, and simplified linkage alignment, etc.

43 • ***FAN NOZZLE.*** Bete Fog Nozzles, Inc., has again a new line of flat spray nozzles. Manufacturer claims more uniform coverage, less waste of spray, side jets of coarse droplets eliminated with the new spray pattern. Called Series F it includes 13 discs with flow rate of from 1/10 to 10 gal./min. and spray angles of 50° to 90°.

44 • ***LINEAR AMPLIFIER.*** For adapting Geiger-Mueller scalers to proportional counting, the Nuclear Instrument & Chemical Corp. has a new model of a linear amplifier. This provides a sensitive amplifier calibrated in millivolts, with a choice of 1 or 10 mv. maximum sensitivity. Has a flat frequency response of 10,000 cycles to 1.5 mc.

45 • ***AIR POLLUTION TEST UNIT.*** The W. B. Conner Engineering Corp. has developed a test unit for determining the amount of contaminants in a given volume of air. Essentially the unit consists of two carbon-filled canisters through which a known volume of air is drawn. The canisters are connected and assembled integrally with a motor-driven air blower, 40 cu. ft. of contaminated air can be drawn through the activated carbon at a linear velocity well within the critical limit of odor break-through. The canisters may be removed from the unit and returned to the laboratory for analysis.

46 • ***STATISTICAL ANALYSIS CALCULATOR.*** For statisticians with control engineering research problems, the Graphic Calculator Co. has introduced a Merrill RMS slide-disk for simplifying computation of standard deviations, root-mean-squares, correlation coefficients, regression lines, etc. The slide-disk is essentially a 10-in. disk that slides and rotates under a pair of vertical and horizontal scales by which a series of right triangles are formed graphically. Operations of squaring, semi-squares, square-rooting, etc., are performed simultaneously. Price $64.

CHEMICALS

47 • ***NON-MELTING WAXES.*** Flexrock Co. developed a series of non-melting waxes expected to have wide application in the chemical industry for packing, etc. Standard waxes that have been treated to make them nonmelting.

48 • ***CEMENT FOR STEEL GRIDWORK.*** Pennsylvania Salt Mfg. Co. offers an illustrated bulletin showing the step-by-step procedure in applying corrosion-resistant cement over steel gridwork. For use in preventing erosion and corrosion of installations in refineries, in feed and return lines, fittings, valves, cyclone equipment, etc.

49 • ***COATING LIQUEFIER.*** American Cyanamid Co. bulletin on Azite 900 liquefier. Used for reducing the viscosity of colloidal solutions, starches, proteins, etc., and in stabilizing the viscosity and retarding the growth of bacteria in these materials when applied to paper. Also gives heat stability and permanence of acidic paper. Bulletin gives properties, charts, etc., applications and formulations.

50 • ***OILS CHART.*** Specifications and uses of oils, acids, and specialties are shown in a new bulletin from Archer Daniels Midland Co. Covers the physical properties, uses, and commercial grades of linseed oils, soybean oils, specialty products, lacquer oils, fish oils, fatty acids, and the chemical products of this company. In addition there are typical physical charts of use to industry.

51 • ***VINYL FILLER.*** A technical information bulletin of the Diamond Alkali Co. on evaluating inert fillers in vinyl plastics. Covers more than a dozen commonly used materials giving cost and showing effects of loading, tear properties, tensile strength, etc.

52 • ***HYDROLUBES.*** A 12-page booklet from Union Carbide & Carbon Corp. on hydrolubes giving physical properties, advantages and how to use the fire-resistant hydraulic fluids which are essentially combinations of ethylene glycol and synthetic polymers.

53 • ***INDUSTRIAL CHEMICALS.*** Tennessee Eastman Co. publication of a 1951 catalog of industrial chemicals. Includes specifications, properties and typical uses of 55 industrial chemicals.

54 • ***ETHYLENE CHLOROBROMIDE.*** A technical data sheet on ethylene chlorobromide describing and giving the properties, analyses, toxicity, and suggested uses as well as organic synthesis. Offered by Westvaco chemical division. Intended as a solvent, intermediate, and fumigant.

55 • ***SLIME CONTROL.*** Santophen 45, a technical grade of sodium trichlorophenate, is being offered by the Monsanto Chemical Co. for the control of slime in industrial cooling waters. Chemical liberates trichlorophenate which is specific against microorganisms producing slime. Bulletin gives properties, biological activity, recommended dosage, instructions for handling, etc.

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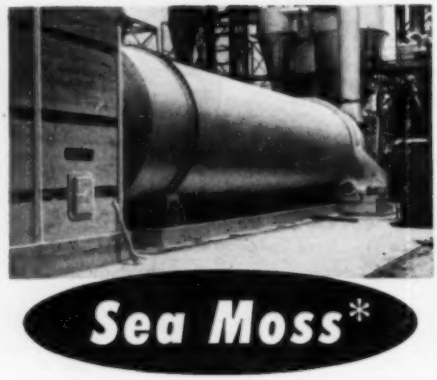

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The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Committee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before *May 15, 1951*, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

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James B. Cull, *Richmond, Calif.*
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Carl D. DeBord, *Midland, Mich.*
D. V. Fletcher, *Kennett Square, Pa.*
Robert J. Fritz, *Baton Rouge, La.*
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Hugh S. Graham, *Bethlehem, Pa.*
John F. Griffith, *Pottstown, Pa.*
John V. E. Hardy, *Wilmington, Del.*
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Charles S. Steiner, *Homewood, Ill.*
William E. Swisher, *Paden City, W. Va.*
Nels E. Sylvander, *Bridgeville, Pa.*
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A. O. Zoss, *Berkeley Heights, N. J.*

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(*Continued on page 42*)

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Edward Lawrence Moore, *Amsterdam, N. Y.*
Herbert A. Morrissey, *Pittsburgh, Pa.*
Don L. Morrison, *Rodeo, Calif.*
Allen L. Mossman, *Schenectady, N. Y.*
Richard W. Moyer, *Cresson, Pa.*
George J. Nebel, *Grosse Pointe, Mich.*
Adin A. Nellis, Jr., *Marcus Hook, Pa.*
Herbert H. Nierman, *Cornelius, Ore.*
Paul F. Opitz, *Monsanto, Ill.*
Herbert Otani, *Plainfield, N. J.*
Myron Pfeifer, *Louisville, Ky.*
Robert E. Potter, *Orange, N. J.*
Carl E. Pruiss, *Ft. Wayne, Ind.*
James R. Randall, *St. Albans, W. Va.*
Robert A. Reinecke, *Lorain, Ohio*
Joseph Reis, Jr., *Haddon Heights, N. J.*
William J. Rice, *Washington, D. C.*
Stuart H. Rider, *Longmeadow, Mass.*
Lee W. Rivers, Jr., *New Castle, Del.*
Andrew Robertson, *Richmond, Va.*
James E. Rogers, *Houston, Tex.*
James H. Rogers, *San Francisco, Calif.*
Jonathan P. Rogers, *Anniston, Ala.*
Glen D. Schaaf, *Lorain, Ohio*
Marvin Baker Schaffer, *Brooklyn, N. Y.*
Louis Schiffman, *New York, N. Y.*
Roy E. Schneider, *Chicago, Ill.*
Michael C. Schultz, *Terre Haute, Ind.*
Herbert Schuyten, *El Segundo, Calif.*
Leo A. Sears, *Wilmington, Del.*
H. Robert Sharbaugh, *Clayment, Del.*
Russell O. Shelton, *Bartlesville, Okla.*
Sal J. Silvis, *Brooklyn, N. Y.*
John C. Simons, Jr., *Pittsburgh, Pa.*
Elbert C. Smith, *South Amboy, N. J.*
Floyd S. Smith, *Auburn, Ala.*
William H. Stein, *Los Alamos, N. M.*
Winthrop P. Stevens, Jr., *Charleston, W. Va.*
Edward E. Stewart, *Richmond Heights, Mo.*
Herschel L. Stewart, *Chicago Heights, Ill.*
James C. Stone, *Baytown, Tex.*
Richard W. Stover, *Buffalo, N. Y.*
Lawrence E. Swabb, Jr., *Cincinnati, Ohio*
Richard John Talamo, *Univ. Heights, Ohio*
Joseph P. Tassoney, *McKeesport, Pa.*
Joseph W. Taylor, *Wilmington, Del.*
Charles W. Ternes, *Baton Rouge, La.*
Lynn A. Treacy, *Seattle, Wash.*
K. S. Treviranus, *Ringwood, Ill.*
Joseph L. Viola, Jr., *New York, N. Y.*
S. L. Wang, *St. Louis, Mo.*
Gustav Warner, Jr., *Hammond, Ind.*
Harold E. Warren, *El Dorado, Ark.*
Philip J. Wendel, *Bristol, Pa.*
Alfred H. Wendelbo, Jr., *Minneapolis, Minn.*
William J. Whitaitt, *Appleton, Wis.*
Edward R. Winiarczyk, *El Dorado, Ark.*
R. B. Wooster, *New York, N. Y.*
H. Neil Worsham, *Tulsa, Okla.*
Louis E. Wuelpern, *Saginaw, Mich.*

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3. Delaware, Ohio—Cyclator—Plating Wastes
4. Lockland, Ohio—Accelator®—Plating Wastes
5. Plain City, Ohio—Cyclator—Plating Wastes
6. Rockdale, Ohio—Cyclator — Asbestos Board Wastes
7. Sandusky, Ohio—Cyclator — Metal Finishing Wastes
8. Botzwood, Pa.—Cyclator—White Water
9. Bridgeport, Pa.—Cyclator—White Water
10. Conshohocken, Pa.—Cyclator — White Water
11. Erie, Pa.—Cyclator—Plating Wastes
12. Grove City, Pa.—Accelator —Hydroblast Waste
13. Johnsonburg, Pa.—Cyclator—White Water
14. Miquon, Pa.—Cyclator—White Water
15. Norristown, Pa.—Cyclator — Asbestos Board Wastes
16. Philadelphia, Pa.—Cyclator—Refinery Wastes
17. Reading, Pa.—Cyclator—White Water
18. Saegerstown, Pa.—Clarifier—Tank Car Washing Wastes
19. Spring City, Pa.—Cyclator—Bleachery Wastes

THESE INFILCO TREATING PLANTS ABATE POLLUTION TO MEET STATE BOARD REQUIREMENTS ECONOMICALLY

Ohio and Pennsylvania are making rapid strides in returning rivers and lakes to their natural state by cleaning up industrial plant effluents . . and Infilco Equipment is helping them to do it!

The industries shown here have found the installation of Infilco Equipment the *best* solution to their waste treatment problems. Many of the plants are recovering by-products or clarified water to defray operating expenses. Infilco can help *you* with *your* waste disposal problems with 57 years experience and a complete line of equipment for chemical and biological treatment. Call in the nearest Infilco field engineer or write to our Tucson offices.

Bulletin 70-A describes Infilco Equipment and its waste treatment applications. Send for it today.

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Quality Engineered for Quality Performance

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INFILCO INC.

TUCSON, ARIZONA

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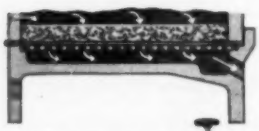
WORLD'S LEADING MANUFACTURERS OF WATER CONDITIONING AND WASTE TREATING EQUIPMENT

HIGH FLOW RATES WITH SPARKLER FILTERS

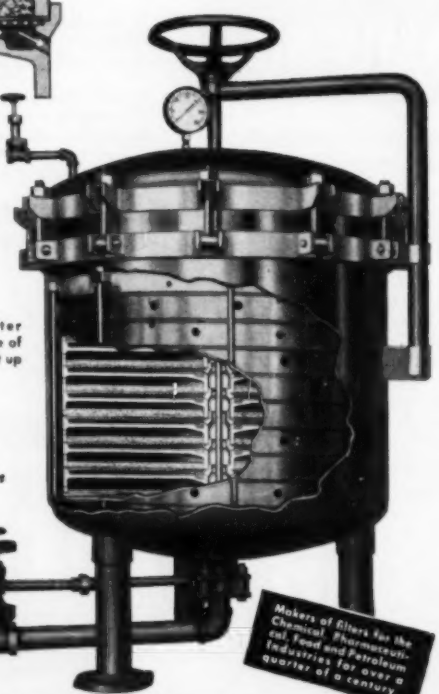
. . . frequently two to five times as high as the flow through filter septa lying in a different plane.

In Sparkler filters, friction encountered in high flow and high viscosity operations is reduced to a negligible factor by the free drainage and uniformity of cake provided by Sparkler's horizontal plate construction. Less operating pressure is needed, with the result that the cake is less dense and thus offers less resistance to flow.

Sparkler horizontal plates permit filter media to be floated into position forming a cake of uniform thickness. Only a thin precoat cake is necessary to assure brilliant clarity of the filtrate right from the start. This means maximum economy of pre-coat material and precoating recirculating time.



Section of filter plate showing perforated metal screen, filter media, and filter cake.



Cutaway view of filter plates showing how cake of uniform thickness is built up on each plate.

Write Mr. Eric Anderson for personal engineering service on your filtering problem.

Makers of filters for the Chemical, Pharmaceutical, Food and Petroleum Industries for over a quarter of a century

SPARKLER MANUFACTURING COMPANY Mundelein, Ill.

KANSAS CITY MEETING

(*Continued from page* 18)

Plant Trips

Trips to industrial plants in the Kansas City area are scheduled for each afternoon Monday through Wednesday. Plants on the schedule include:

General Mills—One of the most modern and up-to-date flour mills in the U. S., and third in size of all General Mills plants.

Cook Paint and Varnish Co.—A leading manufacturer of paints, varnishes, and related materials.

The Hawthorne steam power generating station of the Kansas City Power and Light Co., now under construction.

Midwest Research Institute and Linda Hall Library (see March Chemical Engineering Progress).

Department of Chemical Engineering, University of Kansas, Lawrence, Kan.

Standard Oil of Indiana, Sugar Creek refinery, and its 25,000 bbl./day fluid catalytic cracking unit.

Sheffield Steel plant for the production of special steels from scrap iron.

Corn Products Refining plant for the production of dextrose, corn sugar, syrups, starches, and related materials.

Owens-Corning Fiberglas plant for the production of glass wool and fiberglas insulation.

Procter & Gamble plant for modern production of synthetic detergents and soap products.

On Thursday, May 17, following the formal meeting, an all-day trip to the Spencer Chemical plant near Pittsburg, Kan., is scheduled. Facilities will be shown for the production of ammonia, methyl alcohol, nitric acid, ammonium nitrate and related products. Rail transportation is available by special cars and a complimentary luncheon will be served by the Spencer Chemical Co.

The social program includes, in addition to the Sunday evening warm-up, a Tuesday evening cocktail hour and banquet with entertainment.

Ladies' Program

To encourage the ladies to come to Kansas City with their husbands a complete program has been arranged for their entertainment, in addition to the Sunday evening and Tuesday evening social functions. Arrangements have been made for a tour on Monday of Luziers, cosmetics manufacturers, a luncheon, and a tour and fashion show at the Donnelly Garment Co. The activities on Tuesday include a tour of the William Rockhill Nelson Gallery of Art, a luncheon, and a visit to the Hall Brothers plant for the manufacture of greeting cards.

(*The End*)

SECRETARY'S REPORT

S. L. TYLER

THE Executive Committee of the Institute met on March 11 at the Greenbrier Hotel, White Sulphur Springs, W. Va. The usual routine matters of review of Minutes, receipt of the Treasurer's report and approval of bills were the first order of business. The candidates listed in the February Issue of C.E.P. with the exception of one who is being held for further investigation at the request of the Committee on Admissions, were elected to the grades of membership indicated. There were also 229 applicants elected to Student Membership.

A. V. Forbes, J. C. Landwehr, P. G. McCullough, J. B. Moore and A. J. Wilson were added to the Suspense List because of their having recently entered the Armed Forces of the U. S.

J. H. Perry was appointed to the Committee on the Future of the Institute. F. B. West and A. W. Low were appointed to the Local Sections Committee; J. W. Casten, C. C. Chapman, W. J. Folan, E. B. Gunyou and G. W. Parks were appointed to the Membership Committee and J. W. Casten and R. M. Hubbard were appointed to the Public Relations Committee.

The following members were appointed to the committees of E.J.C. as representatives of the Institute: E. P. Stevenson (Committee on Engineering Sciences); L. W. Bass (Committee on Increased Unity in the Engineering Profession); W. L. McCabe (Committee on Constitution and By-Laws); J. T. Cox (Committee on U. S. Civil Service); S. D. Kirkpatrick (Department of Defense); W. I. Burt (Labor Legislation Panel) and W. L. McCabe (Executive Committee).

Resignations were received from four Junior Members.

H. S. Isbin was appointed counselor of the student chapter at the University of Minnesota to succeed R. Stephenson.

The Council of the Institute met at the Greenbrier Hotel, White Sulphur Springs, W. Va., on March 11, 1951. Minutes of the Executive Committee and Council meetings were approved.

C. G. Kirkbride, chairman of the Membership Committee, reported on the activities and future plans of his committee. He reported that satisfactory results were being obtained through the cooperation of membership committees in the local sections, many of which are just getting started with their activity so that even better results may be expected in the future.

The budgets of both the Institute and C.E.P. were reviewed in the light of actions taken since Jan. 1 and approved.

A REGULAR SERVICE OF THE **COOPER ALLOY** FOUNDRY CO., HILLSIDE, N. J.

CA Technical Topics

MAGNETISM IN AUSTENITIC STAINLESS STEEL

NORMAN S. MOTT
Chief Chemist and Metallurgist

IN THE normal specification range for the 18-8 chromium-nickel stainless steels, especially when the carbon is low, ferrite and the resultant magnetism will often be found. It must not be construed, however, that this condition is detrimental to the properties of stainless steel; in fact, in many cases it is highly desirable.

The fully austenitic stainless steels, when heated in the carbide precipitation range (900-1600° F.) have their carbon precipitated as chromium carbide along the grain boundaries. This depletes the boundaries of chromium with the result that the alloy becomes susceptible to intergranular corrosion.

When alloys containing amounts of ferrite from 5-15% are heated in this temperature range, it is found that carbides tend to form predominantly in the ferrite areas. Since these areas are disconnected and well distributed, the condition does not promote intergranular corrosion.

Stainless steels with free ferrite up to 30% in amount retain good mechanical properties, although they show a slight decrease in ductility and toughness. Their strength and hardness are increased.

Estimation of the presence and approximate amount of ferrite may be accomplished by the use of a phase diagram based upon nickel and chromium equivalent values.* The nickel and chromium equivalent values are computed by the equations:

$$Ni^e = Ni\% + 0.5\ Mn\% + 30\ C\%$$
$$Cr^e = Cr\% + Mo\% + 1.5\ Si\% + 0.5\ Cb\%$$

The boundary line between fully austenitic alloys and those which contain ferrite is expressed by the equation:

$$Ni^e = \frac{(Cr^e - 16)^2}{12} + 12$$

When a higher percentage of nickel is specified in type 316 moly bearing alloys in order to make them completely austenitic in structure, they become susceptible to intergranular corrosion, and if they are to be heated in the carbide precipitation range, as would occur during welding, additions of columbium are required to counteract this susceptibility.

Molybdenum additions to 18-8 stainless make the alloy magnetic due to the formation of ferrite, and existing data have shown that the presence of this ferrite does not interfere with the high corrosion resistance of the alloy. In this form, it enjoys a wide range of usage where excellent resistance to corrosive media and the effects of welding heat are required.

* A. L. Schaeffler, Metal Progress, November, 1949, p. 680-B.

Available on Request

Copies of this article, printed on heavy stock and in form convenient for filing, will gladly be sent to you, without obligation, in small quantities. You will find this excellent for answering problems that arise concerning the subject of magnetism in stainless steel. Address your requests to Publicity Dept., The Cooper Alloy Foundry Co., Hillside 5, N. J.

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DURALIZED FURNACE ROLLERS
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And what is "Duralizing"?
It's a surface treatment given to the casting
1 . . . to make it more resistant to abrasion
2 . . . to make it more resistant to molten metal
3 . . . to minimize "pick up"

This is a treatment we developed in our own laboratory and foundry to meet special conditions for certain furnace operations. Normal high alloy castings would withstand the heat all right but abrasion, erosion and pick up were something else again. The "Duralized" Rolls solved the problem.

While you may not need a high alloy casting calling for the Duralizing treatment, you may have a high alloy casting problem. We'll be glad to study it with you and recommend the alloy and type of casting best for your requirements.

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METAL GOODS CORP. Dallas • Denver • Houston • Kansas City • New Orleans • St. Louis • Tulsa

LOCAL SECTION

TEXAS PANHANDLE

A meeting was held at Bunavista, Tex., Feb. 14 at which W. B. Polk and C. C. Chapman were appointed chairmen of the public relations and membership committees, respectively.

The business session was followed by a talk by W. H. Plowman of Goulds Pumps, Inc. He discussed problems related to the installation and operation of centrifugal pumps.

At a previous meeting Andries Voet, director of ink research, J. M. Huber Corp., spoke on "Printing Ink." His talk gave an insight into the problems involved in the research, mechanical application and properties of printing inks. The officers of this section are as follows:

Chairman.....N. D. Steele
Vice-Chairman.....R. E. Weis
Secretary.....H. W. Hennigan
Treasurer.....P. C. Husen
Directors.....S. E. Forsyth and W. B. Polk

Reported by W. B. Polk

WASHINGTON CHEMICAL ENGINEERS' CLUB

About 45 members and their guests attended the March 9 meeting, held at the Naval Gun Factory. The main feature of the evening was a sound film by Richard L. Tuve, Naval Research Laboratory, on "Navy Experiments in Fighting Large Oil Fires." Mr. Tuve showed the development of a stable protein emulsion which could be pumped into flaming tanks of oil beneath the surface and blankets the fire.

Officers elected for the 1951-52 year are:

President—R. D. Sheeline, Navy Bureau of Ordnance
Vice-President—W. T. Read, Army G-4.
Treasurer—W. D. Kavanaugh, American Cyanamid Co.
Secretary—D. P. Herron, Atlantic Research Corp.

Reported by D. P. Herron

ST. LOUIS

The section held its meeting Feb. 20 at the York Hotel. R. L. Geddes of Stone and Webster Engineering Corp., Boston, talked on "Capacity and Efficiency of Fractionators." He particularly stressed the effect of foam on the operation of bubble-plate columns, and said that it has been shown that foam causes a high friction loss. In years past this fact was often not recognized.

Reported by A. T. Pickens

NEW JERSEY

Filtration Symposium

An all-day technical symposium will be presented by the New Jersey Section at its annual meeting May 8, 1951, in the Hotel Essex House, Newark, N. J. The morning session, beginning at 9:00 A.M. will be comprised of four papers on the theory and practice of filtration. Recent theoretical advances, selection of filters and filter cloths, and feed preparation will be discussed by S. A. Miller, University of Kansas, H. P. Grace, DuPont Co., E. G. Smith, consultant, and C. Fuhrmeister of Oliver United Filters.

A luncheon and business meeting will precede the afternoon session, which will consist of four general presentations. M. Coler of the Markite Co. will talk on protective coatings. The manufacture of cold rubber will be the subject of a talk by G. E. Shriver, U. S. Rubber Co. T. P. Forbath, Chemical Construction Corp., will describe the new sulfuric acid process; and finally G. N. Harcourt, of Buflovak will discuss atmospheric and vacuum drum drying.

Reported by D. A. Levenson

LOUISVILLE

At the April 10 meeting of this section Calvin J. Kummer of the Carrier Corp. spoke on "Industrial Refrigeration." Mr. Kummer is now sales engineer of the Cincinnati office of the Carrier Corp.

He discussed types of industrial refrigeration machines and their applications.

At its March meeting the section heard Charles Cusik of the Brown Instrument division of the Minneapolis Honeywell Regulator Co. speak on "Flow Meter Application." Mr. Cusik drew upon his 23 years' experience in the design and application of flow meters and used slides to illustrate the many applications of flow meters.

Reported by S. D. Neely

DETROIT JUNIOR GROUP

This section held a meeting March 7, 1951, in the Junior Room of the Rackham Memorial. Thomas H. Vaughn, vice-president of Wyandotte Chemicals Corp., gave a talk entitled, "Economic Evaluation of Research Projects." He emphasized the effect of the project on the health of the entire organization. Dr. Vaughn then illustrated with a hypothetical research program and a hypothetical company and then demonstrated the general procedure that Wyandotte uses in its continuus evaluation of its research projects.

Reported by W. W. Jones

Lapp

AUTO-PNEUMATIC

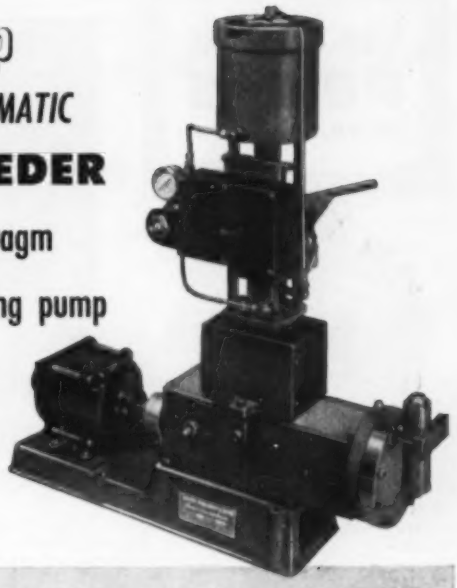
PULSAFEEDER

piston-diaphragm

chemical metering pump

with automatic

output control



For automatic metered pumping of corrosive or "hard-to-handle" chemicals, the Lapp Auto-Pneumatic Pulsafeeder offers new accuracy, efficiency and dependability. Applicable to all pneumatic or electro-pneumatic instrumentation, the Auto-Pneumatic Pulsafeeder provides automatic metering in response to variable flow, pH, temperature, liquid level, pressure, or other processing variables. The Pulsafeeder accomplishes this with a pump that operates at a constant pumping speed; variable flow results from variation only in piston stroke length, controlled by the pneumatic cylinder. In addition, through a manual ratio control, means is provided for accurate adjustment of output rate independent of instrument air pressure changes. And the Lapp Pulsafeeder is the positive displacement proportioning pump that operates without stuffing box or running seal. Its hydraulically-balanced diaphragm acts as a floating partition which isolates the chemical being pumped from pump parts—to protect against contamination of product or equipment. Entire mechanism inherently explosion-proof.

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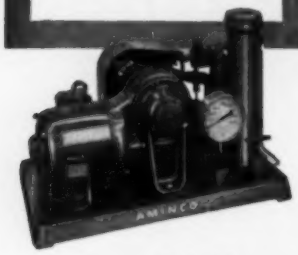
HIGH PRESSURE
PUMPS
UP TO 30,000 PSI



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- GAS COMPRESSORS—Up to 15,000 psi.
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AMERICAN INSTRUMENT CO.
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STUDENT CHAPTERS A.I.Ch.E. MEET

Courtesy of Jack Chichester (Univ. of Detroit)

The First Annual North Central Regional Student Convention was held at Northwestern University, Evanston, Ill., March 3. Students numbering 150 attended the all-day program which included the technical paper presentation, a tour through the Technological Institute, a panel discussion and a dinner and dance in the evening. Schools represented were University of Wisconsin, Northwestern University, University of Detroit, Notre Dame University, University of Michigan, Rose Polytechnic Institute, Illinois Institute of Technology and University of Illinois.

Students winning first, second and third prizes were awarded $30, $20, and $15, respectively. ($45 was donated by Northwestern and $20 by the National A.I.Ch.E.) The winning paper, "Nuclear Reactors," was presented by Robert Rinker, Rose Polytechnic Institute. Joseph Barbieri, Northwestern, took second place with, "Preliminary Report: The Use of Cyclones in Liquid-Liquid Separations and Extractions." Third place was awarded to Keith McHenry, University of Illinois, whose paper was entitled, "Preparation of Triaminoguanidine." All three students were presented with certificates donated by the National A.I.Ch.E. The first two winning students were also awarded one-year subscriptions to Chemical Engineering Progress. The above picture shows Robert Rinker receiving from L. F. Stutzman, chairman, chemical engineering department, Northwestern, the plaque made by the students at Northwestern. The plaque is a brass casting of the A.I.Ch.E. shield mounted on mahogany.

RHODE ISLAND SOCIETY OF CHEMICAL ENGINEERS

At the March meeting Col. Reuel C. Stratton, supervising chemical engineer for the Travelers Insurance Co., talked on, "Insurance—A Phase of Chemical Engineering."

At the February meeting Austin C. Dailey, air pollution engineer for Providence, gave a talk entitled, "Problems of Air Pollution Control." Mr. Dailey discussed the progress which has been made in the Providence area in this matter.

Reported by W. L. Towle

PHILADELPHIA-WILMINGTON

The fifth meeting of the 1950-51 season was held at the Clubhouse Hotel, Chester, Pa., March 13, 1951. Attendance at the dinner was 46 members and guests; approximately 80 persons were present at the meeting that followed.

The speaker of the evening was Dr. P. D. Zemany of the Research Laboratory, General Electric Co., Schenectady. His talk titled, "The Mass Spectrometer in Industry," covered the principles of operation, limitations and advantages.

Reported by William E. Osborn

CHICAGO

This section held its annual social meeting at the Furniture Club of America March 21. After dinner, Dr. Norris Shreve of Purdue University spoke on "Gems and Their Beautifying Qualities." He exhibited a portion of his collection of gems and jewelry.

This section met Feb. 21 in the Western Society of Engineers' suite for dinner, and to hear E. A. Ravenscroft, director of engineering for Abbott Laboratories, speak on "Manufacturing Problems in Producing Pharmaceuticals." After his talk, he introduced J. C. Sylvester, manager of antibiotic research, who described various methods used in discovering and developing antibiotics.

Reported by Thorpe Dresser

BOSTON (Ichthyologists)

Symposium—"The Engineer in Management"

As listed in the Local Section Calendar published in the March issue of C.E.P. page 53, a symposium, the first sponsored by the Boston Section, A.I.Ch.E., was scheduled for April 18, 1951, at the Hotel Lenox, Boston. The program included:

An afternoon session devoted to talks from four speakers, each representing a different area of industrial management; an attempt to be made by each to enumerate those characteristics which best fit an engineer for a managerial position; each to comment on the steps that his organization is taking toward further development of the engineer's "executive potential." These speakers and their respective fields, are:

Earl P. Stevenson, president, Arthur D. Little, Inc., Cambridge, Director, A.I.Ch.E.—Research and Development

W. F. Ryan, engineering manager and vice president, Stone & Webster Engineering Corp., Boston—Engineering

R. M. Couquilette, manager, rubber specialties division, Dewey & Almy Chemical Co., Cambridge—Production

J. L. Gillis, vice-president, Monsanto Chemical Co., and general manager, organic chemicals division, St. Louis, Mo.

A round-table discussion moderated by C. A. Stokes, director of research and development, Godfrey L. Cabot, Inc., Boston, followed by a get-together and dinner.

A keynote address by T. K. Sherwood, dean of engineering, M.I.T. Cambridge, as a conclusion. Dr. Sherwood to analyze the question of "Executive Potential" from the point of view of the engineer-educator; to compare and contrast the training methods employed by industry with those used by educational institutions, and to discuss the steps which the young engineer himself can take to enhance his opportunities for a future in management.

Reported by Laurent Michel

SOUTHERN CALIFORNIA

The March 20 dinner meeting was held at the restaurant of the C. F. Braun Co. in Alhambra. Approximately 103 members and guests attended and heard Edward Glaser, member of Rohrer, Hibler and Replogle, psychoanalytical consultants to management firm, present an outline of their management guidance program. Dr. Glaser explained that the firm's main objective is to provide management with a measurement of the personality characteristics, stature and potential of key personnel.

Reported by G. S. Peterson

New HAMER RIGID LINE BLIND VALVES

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POSITIVE SHUT-OFF BY ONE MAN IN ONE MINUTE *without pipeline movement!*

Hamer RIGID Line Blind Valves solve the problem of effecting a positive blind shut-off in piping installations where endwise movement of the line is impossible. Now, for the first time, the advantages of the safe, speedy, one-man operated Hamer system of blinding can be incorporated in rigid pipe lines and manifolds in refineries, process plants, and on ship board, as original equipment in new installations, or as replacement of existing valves.

New Internal Expansion Feature

The Internal Sleeve takes All the movement

Face-to-face dimensions of Rigid Line Blind Valves conform to A. S. A. Standards for steel wedge gate valves and are not changed when releasing or sealing off the spectacle plate. An internal sliding sleeve, actuated by a ball-bearing mounted ring gear, takes all the movement and eliminates spreading the line.

Examine the cross section and you'll see these other important features. • *Enclosed plate slot*—eliminates loss of product, mess and fire hazard for fluid can't spill while plate is being reversed. • *Rigid body*—unaffected by misalignment or line strains. • *All working parts enclosed*—packed in grease for smooth action; sealed against line fluid. • *Positive shut-off or full-open fluid passage*—There's nothing like a Hamer Line Blind Valve for positive action, easy operation, long service and SAFETY.

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There is a Hamer Line Blind Valve for every blinding application. Illustrated below: 1—Spool-Type, side mounted hand wheel. 2—Spool-Type, upright handwheel. 3—"Tee" and "Ell" Line Blind Valve. 4—Economy 3-Bolt Type.

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23

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Kansas City, Mo., Hotel President, May 13-16. 1951.
Technical Program Chairman: Walter W. Deschner, J. F. Pritchard Co., Kansas City, Mo.

Rochester, N. Y., Sheraton Hotel, Sept. 16-19. 1951.
Technical Program Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.

Annual — Atlantic City, N. J., Chalfonte-Haddon Hall Hotel, Dec. 2-5, 1951.
Technical Program Chairman: Frank J. Smith, Pan American Petroleum & Transport Co., 122 East 42nd St., New York 17, N. Y.

Atlanta, Ga., Feb. 17-20, 1952.
Technical Program Chairman: H. E. O'Connell, Ethyl Corp., Box 341, Baton Rouge, La.

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.
Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Chicago, Ill., Palmer House, Sept. 4-6, 1952.
Technical Program Chairman: George C. Lamb, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.
Technical Program Chairman: R. L. Savage, Dept. Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

SYMPOSIA

Reaction Kinetics
Chairman: B. W. Gamson, Great Lakes Carbon Corp., 333 N. Mich. Blvd., Chicago, Ill.
Meeting—Kansas City, Mo.

Safety in Chemical Plant Operations
Chairman: Matthew M. Braidech, The National Board of Fire Underwriters, 85 John Street, New York, N. Y.
Meeting—Kansas City, Mo.

Light Hydrocarbon Processing
Chairman: Harold Legatski, 1532 Osage Ave., Bartlesville, Okla.
Meeting—Kansas City, Mo.

The Effect of Company Finances on Engineering Expansion
Chairman: J. R. Riley, Jr., Spencer Chem. Co., 610 Dwight Bldg., Kansas City, Mo.
Meeting—Kansas City, Mo.

Maintenance
Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Rochester, N. Y.

Industrial Applications of Photography
Chairman: Carl Gath, Eastman Kodak Co., Kodak Park Works, Rochester, N. Y.
Meeting—Rochester, N. Y.

Round Table Discussion of Chemical Engineering Education
Chairman: W. E. Gift, Tennessee Eastman Corp., Kingsport, Tenn.
Meeting—Rochester, N. Y.

Opportunities in Sales for Chemical Engineers
Chairman: F. J. Curtis, Monsanto Chem. Co., 75 Rust Bldg., 1001 15th St. N.W., Washington 5, D.C.
Meeting—Atlantic City, N. J.

Chemical Engineering Fundamentals
Chairman: W. C. Edmister, Chem. Eng. Dept., Carnegie Inst. of Tech., Pittsburgh 13, Pa.
Meeting—Atlantic City, N. J.

Rapid Reading - and - Effective Speaking
Chairman: L. P. Scoville, Jefferson Chem. Co., 711 Fifth Ave., New York 22, N. Y.
Meeting—Atlantic City, N. J.

Vacuum Engineering
Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.
Meeting—French Lick, Ind.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

SYMPOSIUM—"ION EXCHANGE"

At the symposium on "The Industrial Application of Ion Exchange," to be held at the Mellon Institute, Pittsburgh, Pa., April 20, G. F. D'Alelio, vice-president and director of research, Koppers Co., Inc., will make a few introductory remarks. As announced previously seven papers will be presented. Papers now included in the final program not mentioned in the March issue of C.E.P. include the following:

Some Applications of Ion Exchange in the Dairy Industry—*E. F. Almy, College of Agriculture, Ohio State University, Columbus, Ohio*

(H. E. Otting's paper on the manufacture of special milk products is not included in the final program.)

Recovery of Metals by Ion Exchange—*C. F. Paulson, Permutit Co., New York, N. Y.*

Domestic Applications of Ion Echange—*—G. H. Klumb, Culligan Zeolite Co., Northbrook, Ill.*

Purification of Organic Chemicals by Ion Exchange—*F. H. Kahler, Illinois Water Treatment Co., Rockford, Ill.*

The speaker at the luncheon at Hotel Webster Hall is John F. Laboon, chairman, Allegheny County Sanitary Authority.

This one-day meeting is being sponsored by the Akron, Central Ohio, Cleveland, Ohio Valley, Toledo, and Pittsburgh sections of A.I.Ch.E.

Reported by H. L. Kellner

ROCHESTER

The fifth meeting was the annual joint meeting with the Student Chapter and was held at the University of Rochester in Lattimore Hall March 20.

Sidney D. Kirkpatrick, vice-president of McGraw-Hill and editor of Chemical Engineering, talked on Communication, the Chemical Catalyst. He pointed out the value of writing ability in a chemical engineering career. At a dinner held at the Faculty Club 58 were present and 75 were present at the meeting.

The fourth meeting of this section was held Feb. 21.

The main speaker of the evening was James Hagy of the C. F. Braun Co., who explained certain principles of his company. This was followed by the showing of a film on bubble-cap construction.

There were about 100 present at the meeting and 26 at Lorenzo's for the dinner preceding the meeting.

Reported by O. J. Britton

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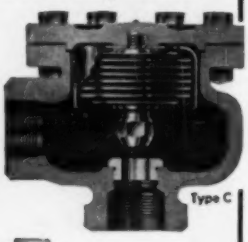

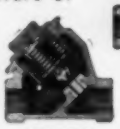

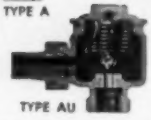

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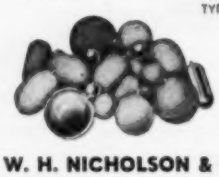

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COLUMBIA VALLEY

This section held a meeting March 8 in Richland, Wash. In the local section technical paper contest J. M. Atwood presented his winning paper, "An Experimental Investigation of Heat Transfer Coefficients from Metal to a Bed of Fluidized Solids." His prize was a year's membership in the A.I.Ch.E., the national society and in the local section. The contest was the first held by this section and was opened to Junior members and those eligible for same.

W. I. Patnode, assistant to the general manager on technical and educational matters, nucleonics department, General Electric Co., completed the program with a talk. Dr. Patnode's talk was titled, "Professional Activities."

At the Feb. 9 meeting at the Desert Inn in Richland, Lloyd Berg, head of the department of chemical engineering at Montana State College, gave a talk on "Synthetic Fuels." Dr. Berg covered the technical and economic aspects of the production of synthetic liquid fuels from coal, natural gas and shale oil.

Reported by H. A. White, Jr.

NORTHERN CALIFORNIA

This section held its monthly meeting at the Engineers' Club in San Francisco March 5. The speaker of the evening was Frederick Sawyer, who directs the air and water pollution research program being carried out by Stanford Research Institute at Stanford, Calif.

His subject was smog, what it is, where it comes from and what can be done about it. Dr. Sawyer pointed out that smog is generally a mixture of atmospheric contaminants not all of which are visible. He declared that legislation has been enacted in a number of cities by local or state action to alleviate smog and declared that private industry can best avoid excessive regulation by taking the initiative to reduce the output of contaminants from industrial operations.

Reported by J. V. Hightower

EL DORADO

The second dinner meeting of this section was held Feb. 16, at the Garrett Hotel in El Dorado, Ark., with 72 members and guests in attendance. Henry D. Noll, a petroleum engineer and manager, engineering and technical service division, Houdry Process Corp., gave an address entitled, "Houdriflow Cracking as Applied to a Modern Refinery."

Mr. Noll traced the development of catalytic cracking and explained the advantages of catalytic cracking over thermal cracking in a modern refinery.

Reported by R. L. Alexander

CHARLESTON, W. VA.

A general meeting of this section was held at the Charleston Recreation Center Feb. 27, 1951. David D. Moore of the Battelle Memorial Institute spoke on "Economics of Future Fuel Supplies." Mr. Moore has specialized for several years on the economics of fuels, including coal, natural gas, and petroleum. Members of the Kanawha Coal Operators Association, A.S.M.E., A.I.M.E., and A.C.S. were invited to attend.

Mr. Moore outlined such economic factors as costs, uses, supplies, reserves, transportation, location, for the three fuels coal, natural gas, and petroleum. In general, Mr. Moore concluded that coal was in the best position for future growth in the next 20 years, petroleum would level off and possibly shrink, and natural gas would grow slightly.

Reported by M. C. Guthrie, Jr.

CENTRAL OHIO

Officers for this section recently elected are:

Chairman.....E. A. Beidler
Vice-Chairman.....J. W. Clegg
Secretary-Treasurer..C. J. Geankoplis
Executive Committee.A. W. Davison
W. B. Kay
K. S. Jacobs

B. W. Gonser, assistant director, Battelle Memorial Institute, talked on March 28 in the Chemistry Building of Ohio State University on "Recent Advances in Chemical Metallurgy." He described the newer chemical processes for recovering the less common metals such as titanium and zirconium. Dr. Gonser is chairman of the rare metals committee of the Electrochemical Society and American manager of the Tin Research Institute.

Reported by C. J. Geankoplis

TERRE HAUTE CHEMICAL ENGINEERS CLUB

The speaker at the March 20 meeting was W. H. Stark of Vulcan Copper and Supply whose talk was entitled, "Trends in the Fermentation Industry." After a brief discussion of the advances made in recent years by the industry in the fermentation processes for antibiotics and vitamins, Dr. Stark covered the aspects of waste sulfite liquor as a raw material source for fermentation of alcohol and butanol.

At a previous meeting D. P. Barnard, research coordinator, Standard Oil Co., discussed "The Principal Fuel Problems." Dr. Barnard gave a résumé of the progress made in gasoline technology since the beginning of the century.

Reported by E. J. Massaglia

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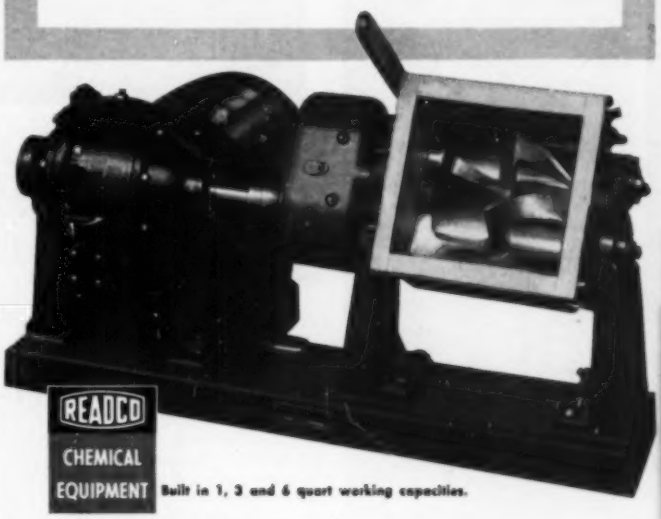

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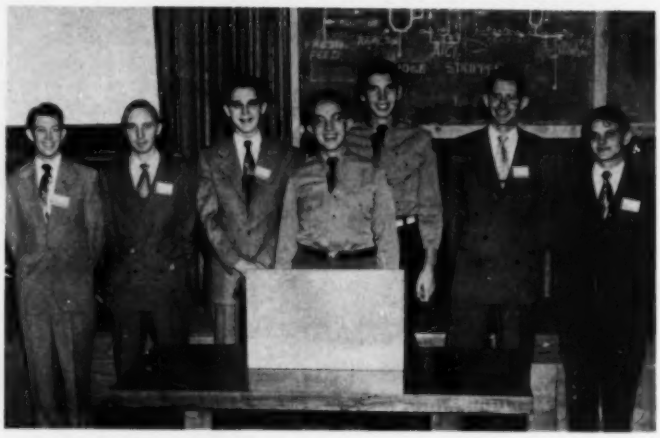
SOUTHWEST A.I.Ch.E. STUDENT CHAPTERS MEET



These seven chemical engineering students presented papers at the first joint meeting of student chapters of A.I.Ch.E. in the Southwest held at Texas A. & M. College, Feb. 9. Left to right they are: G. H. Shoptau and J. O. Moore of the University of Texas; V. F. Schrader, L. T. McBeth, and W. R. Jones of Texas A. & M., and L. E. Westkaemper and H. W. Martin of Rice Institute. Martin and Shoptau won first and second prizes of $15 and $10, respectively, donated by the South Texas Section of A.I.Ch.E. for their papers entitled, "Hydrogen from Hydrocarbons and Steam," and "Polyform and Gas Reversion Processes." Mason Lockwood, consulting engineer of Houston, was principal speaker at a banquet held in connection with the meeting.

AKRON

The March 8 meeting at the University Club with approximately 75 members and guests present featured a talk by H. W. Stoll, Taylor Instrument Companies, Rochester, N. Y., on "Application of Control Instruments to Equipment Used in the Chemical Industry." He stated that chemistry and instruments go hand in hand, naming the variables, temperature, pressure and differential pressure that instrument manufacturers utilize for the operation of their instruments.

About 60 members and guests attended the February meeting of this section held at the University Club. Following the dinner, a coffee talk was presented by E. L. Ulrich who spoke on investments and stocks.

The main speaker of the evening was R. T. Kidde, Hills-McCanna Co., Chicago, who spoke on "Saunders Patent Valves and the Latest Developments in Flow Control."

A brief history of the development of the Saunders valve preceded its detailed demonstration and its operation.

Reported by Edmund Duplaga

SOUTH TEXAS

Members of this section participated in a joint meeting with the local section of the National Association of Corrosion Engineers Feb. 16. Two plants of the Federated Metals division of American Smelting and Refining Co. located in Houston were visited in the afternoon. The inspection trip was followed by a social hour and dinner after which Frank L. Whitney spoke on "Corrosion—An Engineering Problem."

Mr. Whitney's present position is corrosion specialist, general engineering department, Monsanto Chemical Co., St. Louis, Mo. There were 113 present at the dinner and approximately 140 heard Mr. Whitney's talk.

Reported by Henry D. Foster

LOCAL SECTION CALENDAR

NEW JERSEY SECTION: *May 8, Essex House, Newark.* **All-day symposium. Morning Session—Filtration Papers; Afternoon Session—General Papers.**

SOUTHERN CALIFORNIA SECTION: *May 15, Scully's Cafeteria, Los Angeles.*

TERRE HAUTE CHEMICAL ENGINEERS' CLUB: *Apr. 24,* **Commercial Solvents Corp. Speaker, J. H. RUSHTON, Illinois Institute of Technology & Mixing Equipment Co.**

WASHINGTON (D. C.) CHEMICAL ENGINEERS' CLUB: *Apr. 23.* **Spring Symposium: "New Processes for Critical Organics."**

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PEOPLE

Robert D. Scott, Jr., plant manager of the large polyvinyl chloride resin plant at Louisville, Ky., has been appointed general manager in charge of all production for all plants of the B. F. Goodrich Chemical Co.

Joining B. F. Goodrich in 1935, he worked first as a chemist in the rubber reclaim division. He was transferred to the chemical plant in Akron in 1936 as a chemical engineer on polyvinyl chloride resin development. In 1940 he went to Niagara Falls, N. Y., as manager of the company's first vinyl resin plant. When the Louisville Geon plant was completed in 1942, he was then transferred there as plant manager. Scott was graduated from the University of Kentucky in 1934 with a B.S. in chemical engineering and received his Master's degree in that subject the following year from Massachusetts Institute of Technology.

John L. Nelson will succeed Scott as plant manager at Louisville. He has been production manager of the plant. He is a chemical engineering graduate of the University of Wisconsin (1939). He joined B. F. Goodrich organization in that year as a chemist in the rubber reclaim division. He was later transferred to the chemical plant in Akron where he worked on the early development of Geon polyvinyl chloride resin.

When the Niagara Falls Geon plant was completed in 1940 Nelson was transferred there as shift foreman. In 1942 he moved to the newly activated Louisville Geon plant where for four years he served as general foreman and in 1946 was appointed production manager.

William Y. Agnew, consulting chemical engineer of New York, has disposed of his business to R. S. Aries & Associates, consulting chemical engineers, New York. Mr. Agnew whose work has been in pigments, fertilizers and engineering design, was formerly employed by several companies including National Lead, Dorr, and Imperial Chemical Industries. (*See* News item, this issue.)

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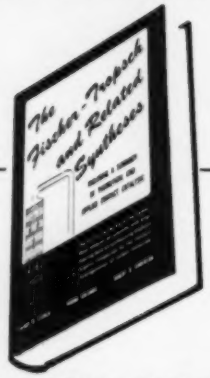

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Manson Benedict has been appointed professor of chemical engineering at the Massachusetts Institute of Technology, Cambridge. Dr. Benedict, who goes to M.I.T. to expand and strengthen the educational program in nuclear engineering, will join the staff on July 1. With his appointment the Institute plans to organize a formal program of education in nuclear engineering, initially at the graduate level.

Dr. Benedict received a Ph.D. in physical chemistry from M.I.T. in 1935. From 1938-42 he worked with the M. W. Kellogg Co. and from 1942-46 was associated with Kellex Corp. in charge of the process design of the gaseous diffusion plant for the concentration of Uranium-235 which was built for the Manhattan Project at Oak Ridge, Tenn. In 1946 he was chairman of the Technical Committee on the Control of Atomic Energy of the War Department.

Prior to his return to the Institute, Dr. Benedict was director of process development for Hydrocarbon Research, Inc. Dr. Benedict is a member of the Atomic Energy and Research Committees of A.I.Ch.E. He is the author of numerous scientific papers on hydrocarbon thermodynamics, separation processes, and physico-chemical measurements. He received the Walker Award of A.I.Ch.E. for his publications on extractive and azeotropic distillation.

BOYD VISITING PROFESSOR AT COLUMBIA

James H. Boyd is visiting professor of chemical engineering, teaching in the present spring session at Columbia University, New York. A consulting chemical engineer since 1947, Dr. Boyd is a specialist in the commercialization of chemical research and its coordination with manufacturing and sales.

A graduate of Kenyon College, Massachusetts Institute of Technology, and University of Pennsylvania, he has been a member of M.I.T. staff, has been associated with the Atlantic Refining Co., Du Pont Co., Phillips Petroleum Co., and the Hycar Chemical Co. During the war Dr. Boyd participated in the synthetic rubber program, assisting in patent and contract negotiations and also served on numerous technical committees.

Dr. Boyd, the author of numerous articles for technical publications, holds a number of patents in such specialties as gasoline manufacture, extraction of lubricating oils, etc.

FORRESTER, SWEARINGEN CHANGE WITH STANOLIND

J. H. Forrester became manager of Stanolind Oil and Gas Co.'s central division Feb. 1. He replaces J. E. Swearingen, division manager in Oklahoma City for the past year, who returns to Tulsa as executive assistant to A. L. Solliday, executive vice-president.

Mr. Forrester has been manager of Stanolind's manufacturing department since Jan. 1, 1947. In that capacity, he directed a plant expansion program that saw the construction of seven new natural gasoline and recycling plants in the three-year period from 1948-50. Design and construction of Stanolind's new synthetic chemicals plant at Brownsville, Tex., was also under his supervision. He joined Stanolind in 1946. Previously, he had been associate director of research and director of technical service for Standard Oil Co. (Indiana). Mr. Forrester was graduated from the University of Wisconsin with a B.S. degree in chemical engineering in 1928. He also holds an M.S. in chemical engineering from Massachusetts Institute of Technology.

DAVIS HEADS CHEMICALS DIV. OF O.P.S.

Appointment of Clark Warren Davis to head the rubber, chemicals and drugs division of the Office of Price Stabilization was announced last month by O.P.S. Director Michael V. DiSalle.

Mr. Davis goes to O.P.S. from the Du Pont Co., Wilmington, where he has been assistant general manager of the Grasselli chemicals department since 1942. The new division director has been with Du Pont since 1917, when he began as a chemist with the company's Eastern Laboratory. In 1928 he became a special assistant with the explosives department, Wilmington, and in succeeding years held a number of executive positions with that department.

Mr. Davis, a native of Gilmore, Neb., is a graduate of Swarthmore (Pa.) College, with a B.S. in chemical engineering (1917).

Bradley Dewey, Jr., was recently elected vice-president of Dewey and Almy Chemical Co., Cambridge, Mass., in charge of the Cryovac division. Dr. Dewey has been in charge of Cryovac operations since last August. The division, which has a plant in Lockport, N. Y., and another under construction at Cedar Rapids, Ia., manufactures Cry-O-Rap plastic bags which are widely used for packaging frozen meat, poultry and fish and smoked and treated pork products. Graduated from Harvard in 1937, and M.I.T. in 1940, Dr. Dewey, who organized the company's product development, has been with Dewey and Almy since his return from the armed forces in 1945.

Thonet C. Dauphiné has been appointed manager of sales development of Hooker Electrochemical Co., Niagara Falls, N. Y. Dr. Dauphiné has been associated with the Oronite Chemical Co. since 1946 as eastern manager of product development and prior to that was a supervising engineer for the California Research Corp. Both Oronite and California Research Corp. are wholly owned subsidiaries of Standard Oil Company of California. From 1936-39, he was an instructor in the chemical engineering department of Massachusetts Institute of Technology from which he has two degrees, S.B. and Sc.D.

REYNOLDS WITH CATALYTIC CONSTRUCTION CO.

Thomas George Reynolds has joined the refinery division of the Catalytic Construction Co., Philadelphia, Pa., as an executive engineer. Mr. Reynolds has been closely associated with petroleum engineering since 1929, when he was an engineering inspector at Standard Oil of Indiana in Whiting. He was subsequently associated with the M. W. Kellogg Co., Continental Oil Co., Foster Wheeler Corp., Kellex Corp., and chief engineer, J. F. Pritchard and Co. Prior to joining Catalytic, Mr. Reynolds was a process engineer with United Engineers and Constructors of Philadelphia.

Mr. Reynolds is a graduate of University of Illinois and was awarded a Masters degree in chemical engineering at Columbia University (1942). A member of several technical societies, he is a registered professional engineer in the State of New York.

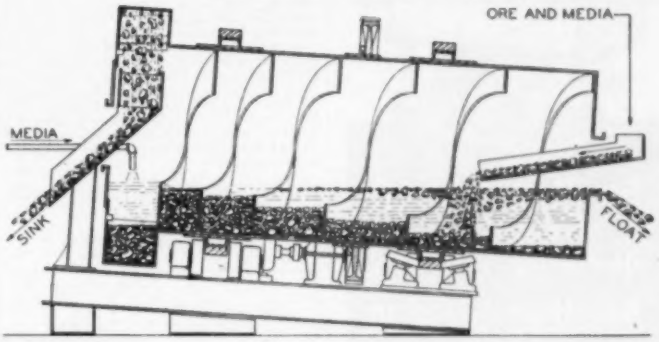
D. D. Walker is now superintendent of the soybean solvent extraction plant now under construction of the Funk Bros. Seed Co., Bloomington, Ill. This plant will process 200 tons/24 hr. of soybeans. Formerly he was associated with the Owensboro Grain Co., Owensboro, Ky., as superintendent.

Paul Kandell has accepted a position with the Bechtel Corp., Los Angeles, Calif., as senior engineer. He was formerly chemical engineer with the Chemical Construction Corp., New York.

William B. Dodge, formerly with the Joseph E. Seagram Inc. as research engineer, is now chemical engineer with the Columbian Carbon Co., Monmouth Junction, N. J.

(More About People on page 59)

COUNTER-CURRENT CLASSIFIERS, HEAVY-MEDIA SEPARATORS



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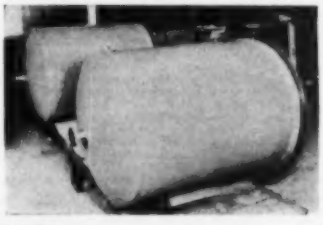

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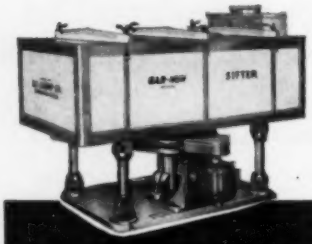

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Send resume of background to Kaiser Aluminum & Chemical Corporation, Post Office Box 1031, Baton Rouge, Louisiana.

Wanted—Associate or full professor of Petroleum Production Engineering in a leading institution. Must have successful professional and research background. Prefer man qualified in phase relationships of oil and gas mixtures, petroleum reservoir engineering and design. Work to begin September fifteenth. Box 1-4.

Chemical Engineers—The Hebrew Institute of Technology (Technion), Haifa, Israel, proposes to make further appointments in the Department of Chemical Engineering. Applications are invited immediately for a full professorship in Chemical Engineering or Industrial Chemistry from applicants with special qualifications in pilot plant work. Applicants should have first-rate professional and academic qualifications and be willing to integrate themselves into the life of the country and, in due course, to teach Hebrew. All applications, with full details, should be sent in the first place, for transmission to Haifa, to the American Technion Society, 154 Nassau Street, New York 38, N. Y., U. S. A., from whom further details may be obtained. The Technion reserves the right to make no appointment to this post if suitable applications are not received. Further vacancies in this department will be advertised in the near future.

SITUATIONS WANTED

A.I.Ch.E. Members

Project and Design Engineer—M.Ch.E., B.P.I. Nine years' experience in process development, production, pilot plant and research laboratory. Rubber, plastics, latex compounding, coatings, adhesives and organic chemicals are my fields. New York City location. Box 2-4.

Chemical Engineer—With varied experience. Presently directing process engineers in overseas refinery. Desire to relocate. Best fitted for responsibility in operations such as assistant superintendent or direction of process analysis, plant startup, development or economics. Box 3-4.

Supervisor-Administrator—Five years' experience drying, milling, evaporation and distillation operations. Desire position production or development work. Knowledge of fermentation; organic chemical processes. P.E. license. Technical societies. Draft exempt; veteran. Married; family. Location immaterial. Box 4-4.

Conscientious — Originally midwesterner. Have family. Seeking permanent small firm tie. Any combination engineering—design, drafting, mechanical or chemical. Small town location northern Wisc. or Mich. Twelve years' engineering covers drafting, design, construction, installation, operation. Salary secondary. No big cities. Box 5-4.

Chemical Engineer—M.S., 25, single. Two years' industrial experience in process development and design. Technical data; honor societies; publications. Desire industrial position. Presently teaching. New York area preferred. Available July 1. Box 6-4.

Supervising Chemical Engineer — B.S.Ch.E. Married, two children. Fifteen years' diversified experience production and development in synthetic organics and pharmaceuticals. Desire position in either production, development or pilot plant operations. Any location. Box 7-4.

Chemical Engineer—31, M.S. 1947, plus advanced work. Process research and development in phosphates and cottonseed; design and construction of equipment at Oak Ridge; heat transfer research. Available August. Box 8-4.

Chemical Engineer—Nine years' thorough experience plant engineering, maintenance, purchasing, plant design, layout, trouble-shooting. Want interesting position requiring creativeness, imagination. Box 9-4.

Chemical Engineer—Ph.D.—Eight years' diversified experience research, development and operating experience petroleum and chemicals. Desire responsible position requiring direction work of others in solution of research and operational problems. Box 10-4.

(*Classified Sec. continued on page 59*)

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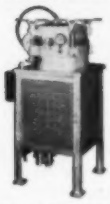

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CLASSIFIED SECTION

(Continued)

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PEOPLE

(Continued from page 57)

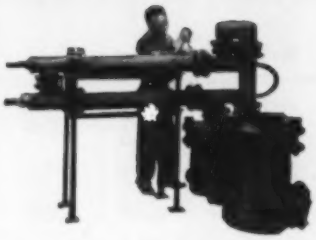
A. A. Melnychuk has been appointed project engineer in the home office of the Omega Machine Co., Providence, R. I. The Omega Machine Co. manufactures chemical feeding equipment.

Mr. Melnychuk holds a Master's degree in chemical engineering. He was president of the Junior Chemical Engineers Organization in New York City in 1947. Prior to his association with Omega Machine Co., Mr. Melnychuk was a project engineer for the National Biscuit Co., and before that was a development engineer with the plastics division of Celanese Corp. In his present assignment he will be working on development and research in the problems of chemical feeding as they occur in chemical industry, foods, plastics, petroleum, pulp and paper, water and sewage, etc.

John Van Nostrand Dorr, chairman of the board of directors of The Dorr Co., has been made a member of the Legion of Honor of the American Institute of Mining and Metallurgical Engineers in recognition of his 50 years of service as a member. This citation took place Feb. 21, 1951, in St. Louis, Mo., at the annual meeting of that Institute.

John W. Cross, associated with Monsanto Chemical Co., was recently named to receive a leave of absence at full salary for an academic year of study. He joined Monsanto in June, 1942, as a chemist in the research department. He was graduated from the University of Pennsylvania in 1942 with a B.S. degree in chemical engineering. At present he is a group leader of the process engineering section in the research department at Everett. In all 21 Monsanto scientists have received academic leaves of absence since 1946.

KNIGHT-WARE
CHEMICAL EQUIPMENT



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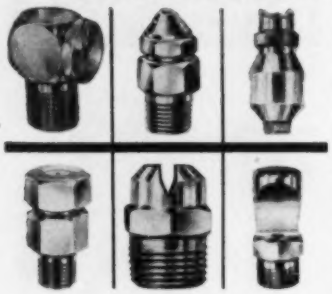

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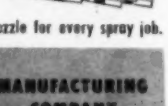

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William R. McLain is now president of Kusan, Inc., in Nashville, Tenn. He was formerly in the plastic division in Henderson, Ky.

L. A. Lundberg is now associated with A. H. Lundberg, chemical engineer specializing in paper pulp in Seattle, Wash.

Edward A. Haagensen, formerly with Great Lakes Carbon Corp., is now manager, Pacific division, Bulkley, Dunton Pulp, Inc., Pasadena, Calif.

James M. McKelvey, formerly instructor in chemical engineering, Washington University, St. Louis, Mo., is now a chemical engineer with Du Pont Co., Wilmington, Del.

Raymond K. Cohen, formerly with Cities Service Oil Co., Tallant, Okla., is now a graduate student at the University of California, Berkeley, Calif.

S. Singh Lamba has been moved to the head office of the Pennsalt International Corp. in the Widener Building, Philadelphia, Pa. His title is regional manager. He was formerly technical engineer in the design and development department at Wyandotte, Mich.

H. P. Morrow is now sales engineer with the Aluminum Company of America, Dallas, Tex. He was formerly located at the company's Pittsburgh (Pa.) office.

James F. Haring is at present engaged as a chemical engineer with the Department of the Interior, Bureau of Mines synthetic oil plant at Louisiana, Mo. He was formerly associated with the Missouri Portland Cement Co., St. Louis, Mo.

E. W. Samoden, formerly with the Calco chemical division of the American Cyanamid Co., has been called back to active duty with the Armed Forces and is located at Picatinny Arsenal, Dover, N. J., as Capt., Ord. Corps.

S. C. Doshi is now serving as assistant superintendent of the caustic plant of the D.C.M. Chemical Works in Delhi, India.

Harry K. Wheeler, Jr., formerly associated with the Standard Oil Company (Indiana) is now technical director, El Dorado refinery, Pan-Am Southern Corp., El Dorado, Ark.

R. A. Williams has left the University of Louisville, Louisville, Ky., and is now affiliated with the Holston Defense Corp., connected with the Tennessee Eastman Corp., Kingsport, Tenn., as a senior chemical engineer.

C. D. Darwin, formerly an independent consultant, is now process engineer in the chemical department, Waterford plant of the General Electric Co., Waterford, N. Y.

Jimmie L. Huitt, a former instructor in chemical engineering at the University of Oklahoma, is now senior research engineer, Magnolia Petroleum Co., Dallas, Tex.

Kenneth H. Hoover is now director of research, R. J. Reynolds Tobacco Co., Winston-Salem, N. C. He was previously with Commercial Solvents Corp., Terre Haute, Ind.

R. A. Gross is now chemical engineer with Pennsylvania Salt Manufacturing Co., Elkins Park, Pa. He was previously employed by Metal Hydrides, Inc.

Joseph Koslov has left Burns & Roe, Inc., and has joined the process engineering department of the Kellex Corp., New York, N. Y.

A. O. Shelby, formerly associated with Phillips Petroleum Co., is presently employed by Rufnek Products Co., Houston, Tex., as chief engineer.

J. N. Rossen is now serving as chemical engineer with the Tracerlab, Inc., Boston, Mass.

Necrology

W. G. KRUMMRICH

William G. Krummrich, vice-president of Monsanto Chemical Co., since late in 1949, and general manager of the organic chemicals division since 1948, died recently. He was 56 years old. From 1917 when he joined Monsanto he was given many assignments first doing analytical work in the laboratory of the John F. Queeny plant in St. Louis. Following a service period with Chemical Warfare Service and after completing a correspondence course in chemical engineering, he held the position of assistant plant chemist, night superintendent, plant chemist and operating superintendent. Still later he was transferred to Monsanto, Ill., as manufacturing superintendent. After an interval of four years he was promoted to plant manager. He was a former chairman of St. Louis Section of A.I.Ch.E.

E. H. FRENCH

Edward H. French, chemical engineer, and long a member of A.I.Ch.E. died recently. He received his education at Ohio State University and was affiliated at the turn of the century with the Independent Chemical Co., Saginaw, Mich. Later he worked for the Norwich Chemical Co., and still later with Hilton & French, Smethport Research & Testing Laboratories, Smethport, Pa.

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An engineering staff of many years experience has specialized on this type of equipment and is at your service. Why not write today, outlining your vacuum problem?

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Mr. Insulation says:

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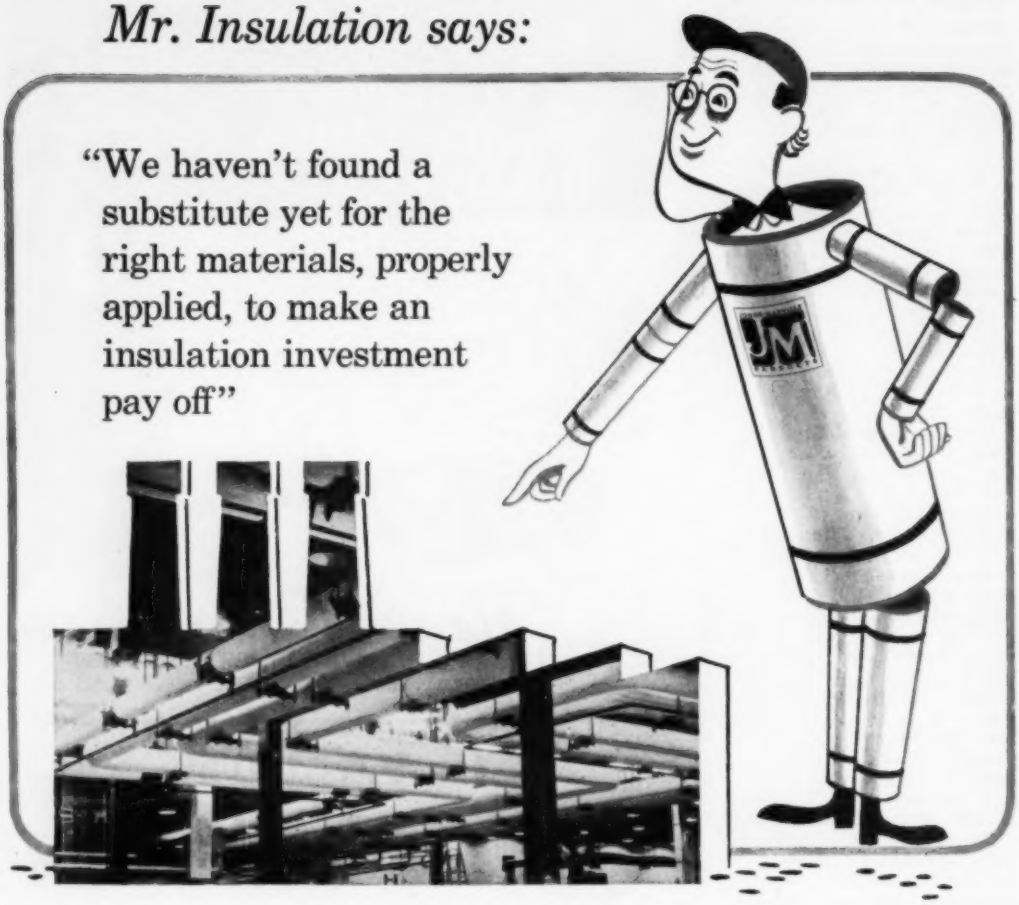

To be successful an insulation job must be properly engineered. In addition, it must have these two important ingredients:

1... THE RIGHT MATERIALS: service conditions vary greatly in industrial applications. That's why no one insulation can serve as a jack-of-all-trades on all jobs. For this reason, Johns-Manville uses asbestos and many other selected raw materials to produce the most complete line of insulations available. These insulations serve applications ranging between the extreme temperatures of 400F below zero to 3000F above.

2... THE RIGHT APPLICATION: Here again Johns-Manville's long experience in the field of insulation can be of value to you. Insulation engineering advice plus the services of insulation contractors trained in Johns-Manville methods of correct application are at your call.

If you are planning an insulation job why not put your problem up to insulation headquarters? Write Johns-Manville, Box 290, New York 16, N. Y.

JM

Johns-Manville *first in* **INSULATIONS**

In this 50th Anniversary year Vulcan recognizes its responsibility for continued high standards of service to the many chemical processing companies throughout the world who have looked to Vulcan for quality equipment and experienced engineering during the past five decades.

VULCAN — CINCINNATI

ENGINEERS AND MANUFACTURERS OF PROCESS PLANTS AND EQUIPMENT

The VULCAN COPPER & SUPPLY CO., General Offices and Plant, CINCINNATI, OHIO

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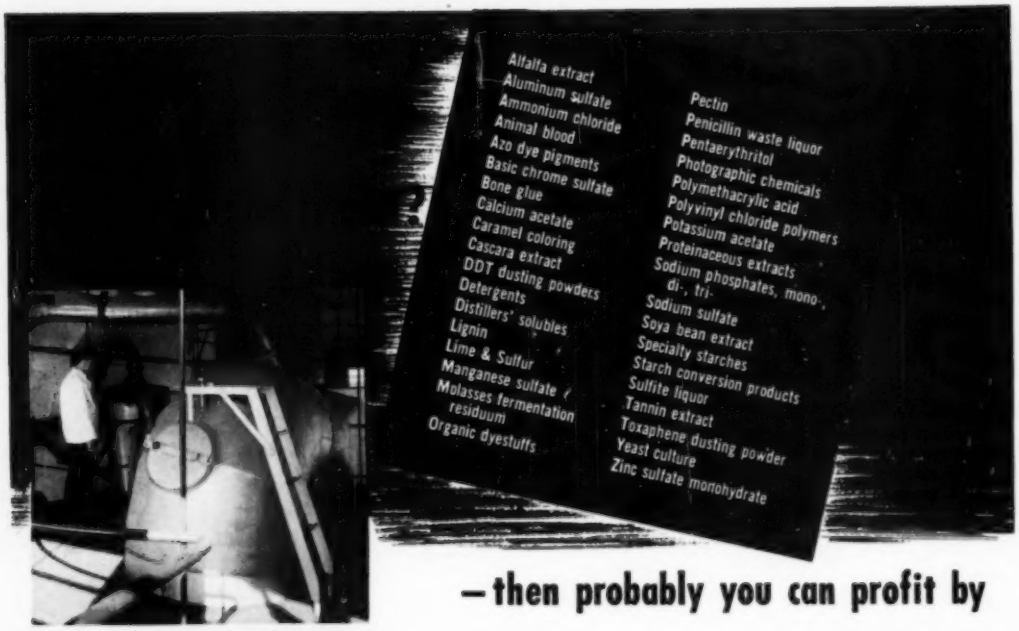

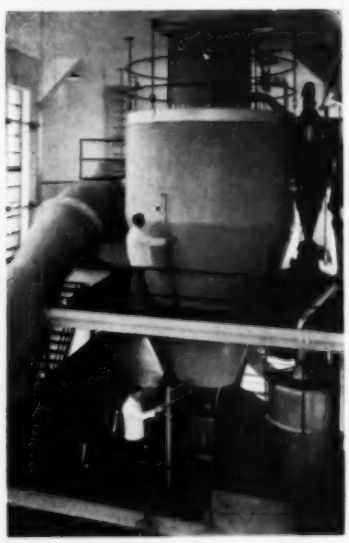

Above photos were taken inside the Swenson Spray Dryer Laboratory

—then probably you can profit by

SPRAY DRYING

By test-drying a typical sample in the Swenson Spray Dryer Laboratory, it can quickly be determined whether or not your material is susceptible to spray drying. Such tests may be arranged at reasonable cost.

As the result of data secured during such test runs, our engineers determine the most efficient, economical design for building production equipment.

Swenson Spray Dryers are now at work on a wide variety of materials, many of which were unknown just a few years ago. If you are working with a new material, do not overlook the economies of spray drying in your process. Swenson engineers are glad to offer every possible co-operation.

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